ALLIS-CHALMERS

STANDARD DEFINITIONS AND NOMENCLATURE

HYDRAULIC TURBINES AND PUMP/TURBINES

ALLIS-CHALMERS CORPORATION
HYDRO-TURBINE DIVISION

54X10084-01

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Price: $5.00

INTRODUCTION

Allis-Chalmers Corporation has published this brochure to make available for general use modern standard terminology concerned with the descriptions, dimensions and performance of hydraulic turbines and pump/turbines. The dimensionless parameters and the graphical presentation of data as illustrated herein represent the most recent developments for computer aided performance analysis and display.

The International System of Units (SI) is used throughout. For the convenience of those, particularly in the United States of America, who are not familiar with the SI units, conversion factors have been included, along with the description of basic and derived SI units. For complete descriptions of the SI units, reference is made to International Standards ISO 1000. A very broad listing of conversion factors may be found in ANSI Z210.1-1976.

It is intended that this brochure will be revised from time to time as further developments in the field require expanded or revised data.

1.0 GLOSSARY

1.1 Scope

This is a compilation of the terminology with descriptions for the principal components of hydraulic turbines and pump/turbines. Also included to facilitate identification and description of the components are drawings representative of various types and configurations of hydraulic turbines as well as certain components. The drawings are listed below and appear at the end of the Glossary.

Figure 1A - *Vertical Fixed Blade Propeller Turbine*
Figure 1B - *Vertical Kaplan Turbine*
Figure 2 - *Vertical Francis Turbine*
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Figure 4 - *Bulb Turbine*
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1.2 Component Nomenclature and Definitions

The terminology and descriptions that are presented below are preceded by an identification number. Each identification number also appears on one or more of the accompanying drawings to assist in identifying the component.

1 Runner — the rotating element of the turbine which converts hydraulic energy into mechanical energy. For reversible pump/turbines, the element is called an *impeller* and converts mechanical energy into hydraulic energy for the pump mode.

1A Runner Buckets (or **impeller vanes**) — the contoured components of Francis and impulse runners that deflect the flowing water and transfer the energy to the runner crown or disc when operating as a turbine; or that transfers energy to the water when the impeller is operating as a pump.

1B Runner Blades — the contoured components of a propeller runner that radiate from the hub, deflect the flowing water and transfer the energy to the runner hub. The blades may be angularly adjustable or rigidly fixed in the hub.

1C Runner Crown — the upper axisymmetric portion (inner shroud) of the runner which provides a mechanical attachment to the main shaft and to which the top, or inner ends of the runner buckets (or impeller vanes), attach.

1D Runner Band — the lower axisymmetric portion (outer shroud) of the runner to which the lower or outer ends of the runner buckets (or impeller vanes), attach.

1E Runner Hub — the axisymmetric portion of a propeller runner which provides the attachment to the main shaft and to which the inner ends of the runner blades attach.

1F Runner Cone — the extension of the runner crown, or runner hub, that guides the water as it leaves the runner.

1G Runner Crown Seal — the close running clearance between the rotating runner crown and the stationary head cover. The close clearance restricts the flow of water into the chamber between the top of the runner and the bottom of the head cover.

1H Runner Band Seal — the close running clearance between the rotating runner band and the stationary bottom or discharge ring. The close clearance restricts the flow of water between the high pressure zone and the low pressure zone of the runner/impeller.

2 Wearing Rings — replaceable rotating rings fastened to the runner or adjacent stationary rings fastened to the head cover and the bottom ring (or discharge ring), thus forming removable seals with small clearances.

3 Spiral Case — the spiral shaped water passage which completely surrounds the turbine providing a uniform distribution of water flow to the turbine. The upstream end of the spiral case connects to the pressure conduit or penstock.

4 Semi-Spiral Case — a concrete intake having direct flow to the upstream portion of the turbine and a spiral case surrounding the downstream portion of the turbine to provide uniform water distribution.

5 Vaned Intake Ring — the structural member in a tubular unit consisting of the outer conical ring, guide vanes and inner ring which supports the main guide bearing.

5A Guide Vanes — the streamlined stationary components that span the waterway to provide support for the guide bearing and to provide direction to the water flowing to the runner.

6 Stay Ring — the structural member surrounding the wicket gates having two annular rings connected by a number of fixed stay vanes in the water passages. Its function is to provide support and structural continuity between the upper and lower portions of the turbine distributor, while guiding the water as it enters or leaves the spiral case (pump or turbine).

7 Stay Vanes — the streamlined stationary members which connect the upper and lower annular rings of the stay ring, and provide a rigid connection for the top and bottom turbine structures.

8 Nose Vane — a stay vane located at the junction of the small and large end of the spiral or semi-spiral case.

9 Bottom Ring — the stationary ring which contains the lower wicket gate bushings, and provides the water surfaces leading to or from the runner band or discharge ring and is bolted to the stay ring. It may be integral or separate from the discharge ring.

10 Discharge Ring — the structural member on a Francis turbine that surrounds the runner band. On a propeller turbine it surrounds the blades and forms a guide for the water. It may be integral with the bottom ring. The draft tube liner is attached to the downstream end of the discharge ring.

TUBE is an Allis-Chalmers Trademark.

11 Draft Tube — the diffuser which regains the residual velocity energy of the water leaving the turbine runner or accelerates the flow as it approaches the pump impeller.

12 Elbow Draft Tube — a diffuser in the form of an elbow.

13 Inlet Valve — the valve or gate that controls the water flow to the turbine.

14 Draft Tube Liner — the steel lining used in the draft tube to protect the concrete from the high velocity of the water.

15 Pier — the structural member used to support the upper surface of the horizontal portions of water passages such as the draft tube and the spiral case inlet.

16 Pier Nose — the steel lining used at the upstream ends of a pier.

17 Main Shaft — the rotating element that transmits torque developed by the turbine runner to the generator rotor or transmits torque developed by the motor to the pump impeller.

17A Coupling Bolts — the fasteners that attach the main shaft to the runner (impeller) and to the generator (motor) or intermediate shaft.

17B Nut Guard — the protective cover over the coupling bolts and nuts.

18 Head Cover — the axisymmetric structural member in vertical machines that spans the top of the distributor, provides the separation between the watered runner chamber and the dry turbine pit and supports the main shaft packing box and the main bearing. In propeller and Francis machines the head cover also supports the upper wicket gate stems and is bolted to the stay ring.

18A Outer Head Cover — the outer section of a circumferentially split head cover that supports the upper wicket gate stems and is bolted to the stay ring.

18B Intermediate Head Cover — the middle section of a circumferentially split head cover that is bolted to the outer and inner head cover section.

18C Inner Head Cover — the inner section of a circumferentially split head cover. It is bolted to the outer or intermediate head cover and supports the main bearing and packing box.

***18D Pressure Balance Line** — the pipe connecting the chamber between the top of the runner crown and head cover outboard of the runner crown seal to the space between the runner band and bottom (or discharge) ring outboard of the runner band seal.

18E Equalizer Line (Thrust Relief Line) — the pipe connecting the chamber between the top of the runner crown and head cover inboard of the runner crown seal to the draft tube.

19 Main Guide Bearing — the bearing located nearest the runner. On vertical machines it is typically a journal bearing. On the standard *TUBE* turbines it is a spherical roller bearing.

19A Bearing Shell — the removable element containing the material that forms the bearing surface.

19B Bearing Shoes — the individually adjustable elements of a segmented type journal bearing.

19C Bearing Housing — the outer casing of the main guide bearing that supports the shell or shoes and usually mounts on the head cover.

19D Oil Basin — the collecting reservoir for the main guide bearing oil. It is normally located just below the guide bearing.

19E Bearing Cover — the radially split cover which closes the oil reservoir and prevents contamination of the bearing oil system.

20 Wicket Gates — the angularly adjustable streamlined elements which control the flow of water to the turbine or discharge from the pump.

21 Gate Operating Ring — the ring rotated by the servomotors which distributes the force from the servomotors to the individual wicket gate linkages to provide simultaneous movement of all wicket gates.

22 Gate Servomotors — the hydraulic cylinders actuated by oil pressure which supply the force necessary to operate the wicket gates through the gate operating ring.

22A Gate Lock — the device used to prevent actuation of the wicket gates by the servomotors.

23 Connecting Rods — the element connecting the servomotor piston rod to the gate operating ring.

24 Gate Mechanism — the components used to actuate the wicket gates consisting of the gate servomotors, the gate operating ring and the gate linkage.

25 Gate Linkage — all connecting linkage between the gate operating ring and the wicket gates.

25A Gate Lever — the arm which is attached to the wicket gate stem to transmit the actuating force from the gate mechanism to the wicket gate.

***25B Thrust Cap** — the disc that supports the wicket gate to maintain vertical adjustment.

***25C Thrust Cap Bolt** — the threaded member that provides for the vertical adjustment of the wicket gates.

***25D Gate Thrust Bearing** — the annular member made of bronze or a similar bearing material that supports the weight of the wicket gate and gate lever.

***25E Thrust Collar** — the ring that transmits axial hydraulic loads from the wicket gate to the head cover.

25F Shear Lever — the lever attached to the gate lever with the shear pin and connected to the gate operating ring through the gate link.

25G Gate Links — the connecting links between the shear lever and the gate operating ring.

25H Shear Pin — the replaceable protective device which is designed to fail by shearing when an obstruction prevents the wicket gate from moving.

25I Gate Link Pin — the pin connecting the shear lever and the gate link.

25J Eccentric Pin — the eccentric type link pin connecting the gate link and gate operating ring. The eccentric construction permits adjustment in the gate linkage to equalize gate closure.

*Identification numbers do not appear on any of the accompanying drawings.

26 Main Shaft Seal — a seal used to minimize leakage at the main shaft.

27 Packing Box — an annular chamber surrounding the main shaft; containing pliable sealing material and having a movable gland permitting adjustment or replacement of the sealing material.

27A H-Ring — the spacer ring inserted between rings of pliable packing which permits a circumferential path for distributing lubricants.

27B Shaft Sleeve — the polished stainless steel (or bronze) ring fastened to the shaft to provide a mating surface for the packing.

28 Check Valve — an air vent that opens on increasing differential pressure between a negative pressure zone in the water passages and outside atmosphere.

29 Wicket Gate End Seals — the metallic or elastomeric strips that are retained in annular grooves in the head cover and the bottom ring to provide sealing contact with the ends of the wicket gates.

30 Flexible Coupling — the shaft connection between the speed increaser and the generator which can accomodate minor misalignment.

31 Turbine Pit — the open space on a vertical unit between the head cover and the generator. It provides access to the gate mechanism, the main guide bearing, and the packing box.

32 Pit Liner — the plate steel lining in the turbine pit. It serves as an internal form and as a protective liner for the surrounding concrete.

33 Turbine Walkway — the platform in the turbine pit which facilitates inspection and servicing of the gate mechanism, the main guide bearing, and the packing box.

34 Air Valve — the adjustable vent for admitting air to a waterway zone near the runner.

35 Water Deflector — the ring attached to the main shaft which slings leakage water outward to the head cover drainage system.

35A Oil Deflector — the ring attached to the main shaft below the bearing which deflects oil into the oil basin.

36 Main Shaft Indicator — the pointer mounted on the bearing cover and aligned with a scribed line on the main shaft. Its purpose is to provide a visual indication of the vertical position of the shaft.

37 Man Door — a door installed to permit access for inspection and maintenance.

38 Turbine Piping — a general term to cover the air, oil, water supply and drainage piping within the turbine pit.

39 Distributor — the assembly which includes the stay ring, wicket gates, head cover and bottom ring. Its "centerline," in a vertical machine, is a horizontal plane equidistant from the top and bottom of the wicket gates.

40 Runner Hub Assembly — the assembly consisting of the runner hub, blades, cone, and including all of the runner blade operating mechanism that is used to adjust the pitch or angle of the runner blades.

40A Runner Blade Trunnion — the shaft segment integral with or bolted to the runner blade. It transfers the rotating action of the operating mechanism to the runner blades and supports the blade in the hub bearings.

40B Rocker Arm — the lever that attaches to the runner blade trunnion and connects to the blade link.

40C Blade Link — the element that connects the rocker arm to the crosshead through the link bolt.

40D Blade Link Bolt — the element that attaches the link to the crosshead and the rocker arm.

40E Crosshead — the member that is integral with the blade servomotor and through links and rocker arms transmits the operating force to all blades simultaneously.

40F Drain Valve — the manually operated valve that is used to drain the oil from the hub.

41 Blade Servomotor — the hydraulic cylinder actuated by governor oil pressure which supplies the force necessary to adjust the runner blades. The piston is stationary and the cylinder barrel (with integral crosshead) moves axially on suitable supports.

42 Blade Tilt — on propeller runner blades the sine of the blade tilt angle is defined as the axial distance between two points on the periphery of the blade (one at the entrance edge and one at the discharge edge) divided by the chord between these two points.

42A Blade Angle — on propeller runner blades the sine of the blade angle is defined as the axial distance between two points on the periphery of the blade (one at the entrance edge and one at the discharge edge) divided by the arc length along the blade periphery between these two points.

43 Servomotor Piston — the stationary element that provides attachment for the oil pipes and separates the high pressure and return chambers within the servomotor.

44 Cylinder Cap — the end cover for the servomotor cylinder that includes an extension to mate with the servomotor support bushing.

45 Speed Increaser — the geared drive unit which increases turbine shaft speed to drive the generator at an optimum speed for power generation. The speed increaser contains bearings that provide the necessary shaft support and thrust capacity.

46 Stay Column Assembly — the structural component which consists of the inner and outer stay cones connected by stay columns and/or stay vanes across the water passage; and which transmits the loads from the bulb unit to the powerhouse structure.

46A Stay Column, Upper/Lower — the structural components that span the waterway to provide support to the turbine and to the generator, transmitting the forces to the powerhouse structure. Both upper and lower stay columns can contain access tubes to the turbine compartment.

*__46B Stay Vane__ — the streamlined structural members which connect the inner and outer stay cones and provide support between the bulb unit and the powerhouse foundation. Stay vanes may be used instead of or in addition to the stay column.

*Identification numbers do not appear on any of the accompanying drawings.

47 Stay Cone, Inner/Outer — the plate steel components that line the inner and outer surfaces of the water passage and function with the stay columns and/or the stay vanes to transmit bulb loads to the powerhouse structure.

48 Outer Gate Barrel — the conical section of the outer wall of the water passage which provides the outer support for the wicket gate stem bushings and, in most cases, for the gate operating ring.

49 Access Tube — the watertight passage providing access between the generator compartment and the powerhouse, and between the turbine compartment and the powerhouse. Frequently, access tubes to the turbine compartment are provided in both the upper and lower stay columns.

50 Bulb — the streamlined watertight housing for the generator.

50A Inner Gate Barrel — the conical section of the bulb that provides support for the inner wicket gate stem bushings.

50B Bulb Nose — the spherical upstream section of a bulb.

51 Oil Pipes — the concentric pipes in the shaft that conduct the oil supplied by the governor for actuation of the blade servomotor and for pressurizing the runner hub.

52 Housing — the enclosure, surrounding an impulse runner, which forms the aerated chamber in which the runner operates.

53 Brake Jet — the water jet that provides the counter-rotational force used to decelerate the runner.

54 Needle — a moving element which is actuated by the governor, the servomotor or by hand mechanism to control the size of the jet impinging on the bucket.

55 Nozzle — the shaped water passage which, with the needle, produces the jet and controls the rate of water flow.

56 Intake Pipe — the connecting water passage from the spiral case to the nozzle assembly.

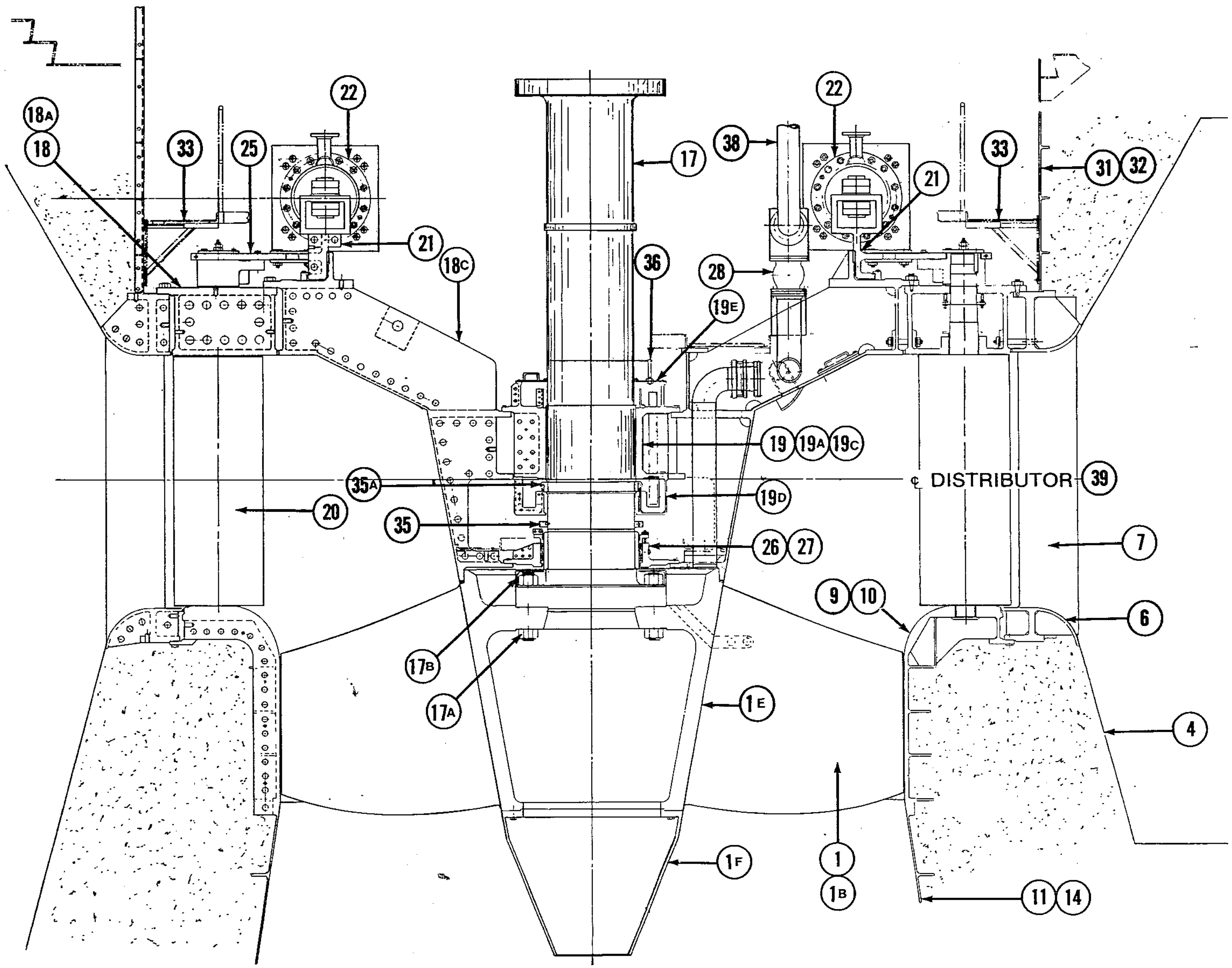
57 Deflector — the device within the housing that is actuated by the governor for deflection of all or part of the jet away from the buckets, and therefore regulating the power output with a minimum effect on flow.

58 Instrumentation — the devices that sense temperature, flow, pressure, liquid level or RPM, and provide visual indication and/or electrical signals so that control functions can be energized manually or automatically.

59 Vent — the piping that provides atmospheric air to internal chambers for ventilation and pressure equalization.

60 Erection Joint — a slip joint that permits relative movement between adjoining parts. Leakage is controlled by a suitable seal arrangement.

Fig. 1A — Vertical Fixed Blade Propeller Turbine



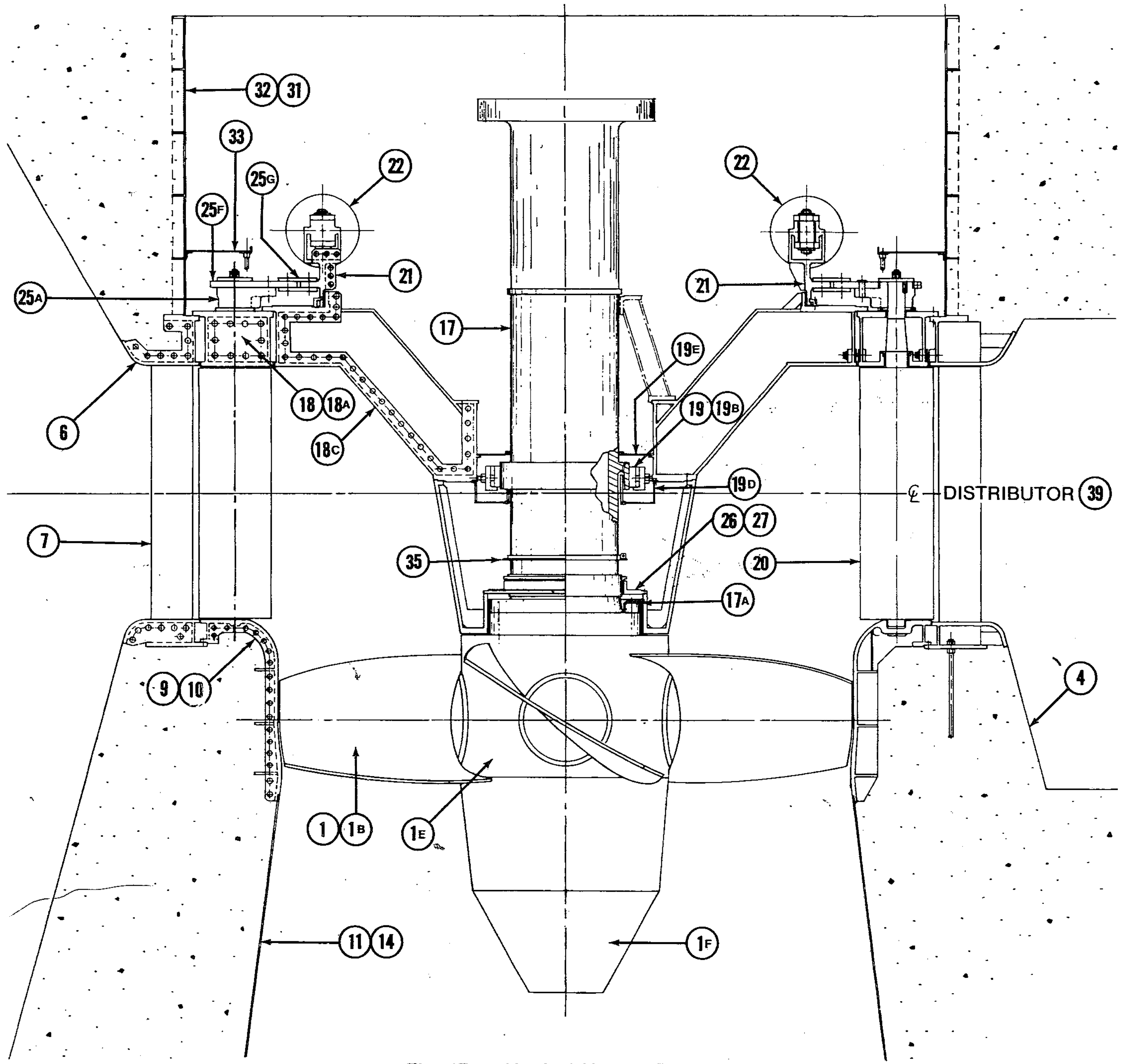
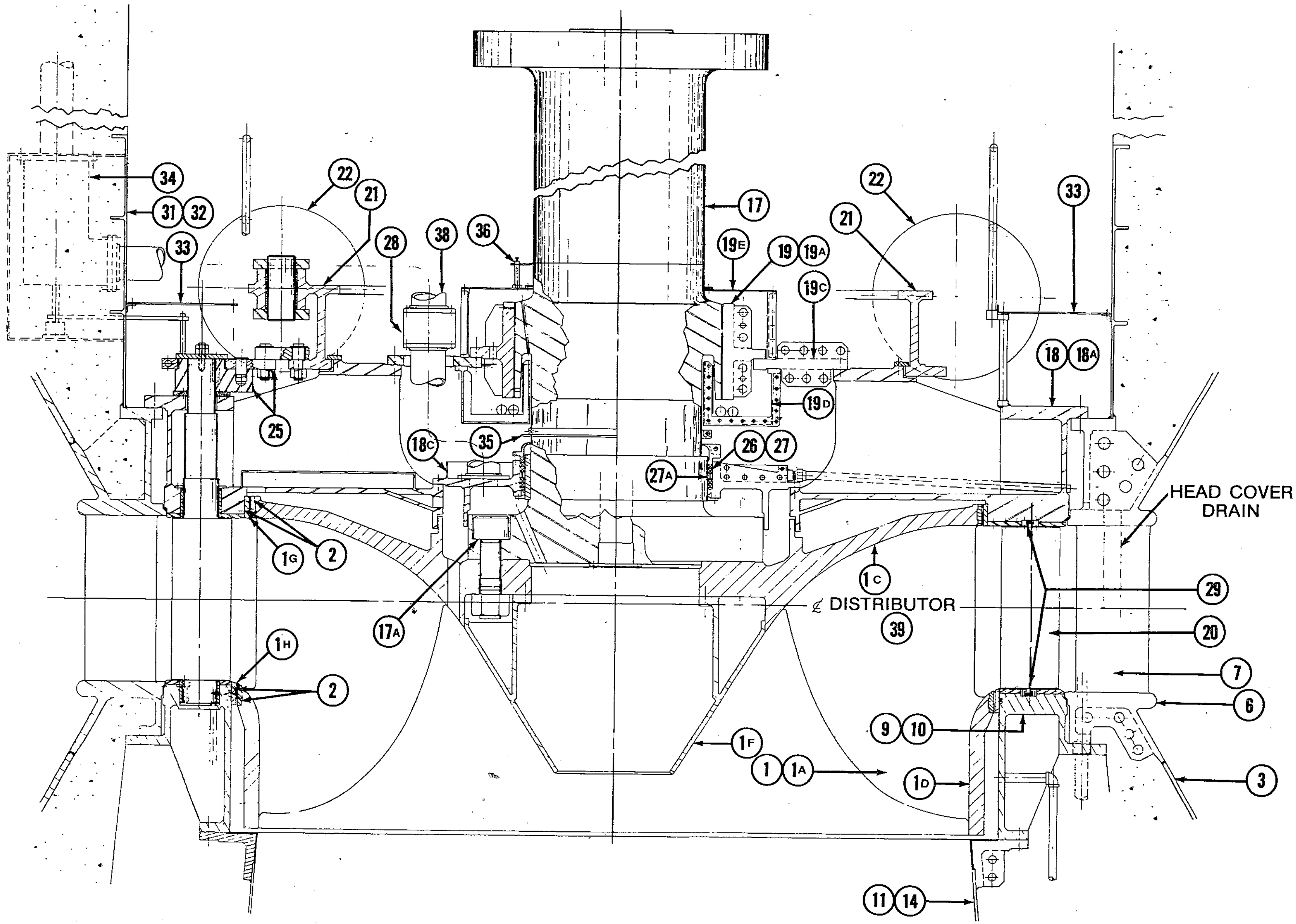


Fig. 1B — Vertical Kaplan Turbine

Fig. 2 — Vertical Francis Turbine



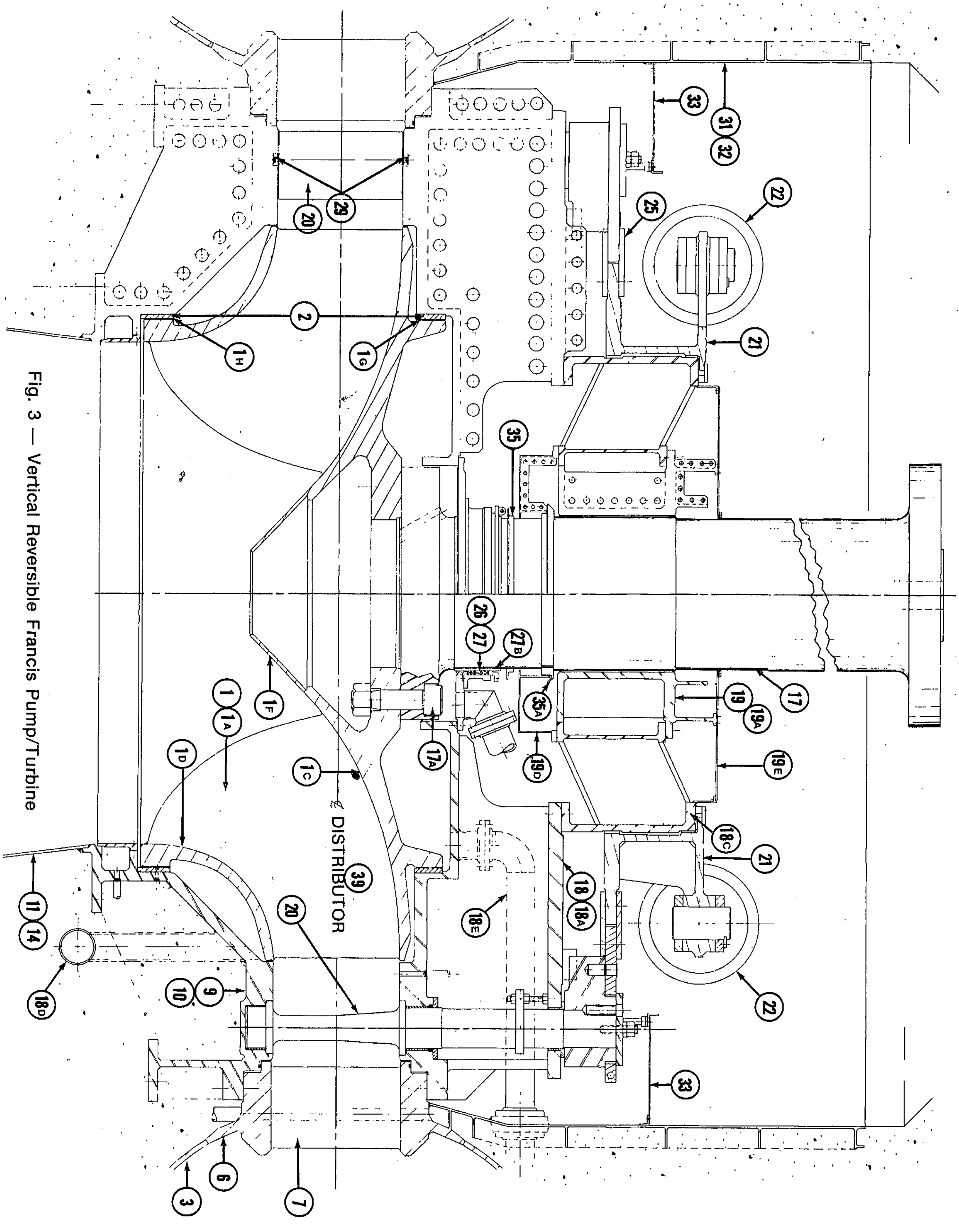
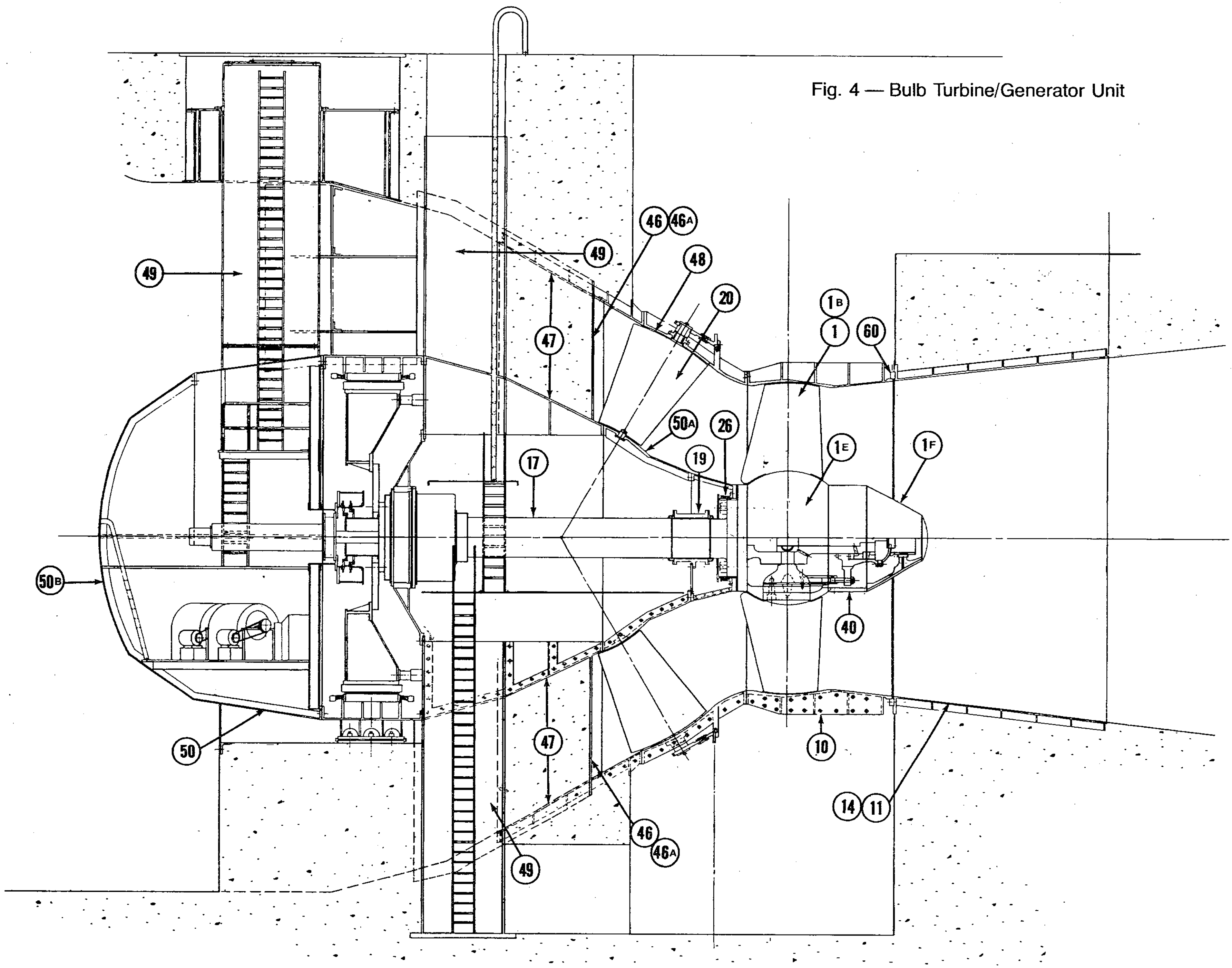


Fig. 3 — Vertical Reversible Francis Pump/Turbine

Fig. 4 — Bulb Turbine/Generator Unit



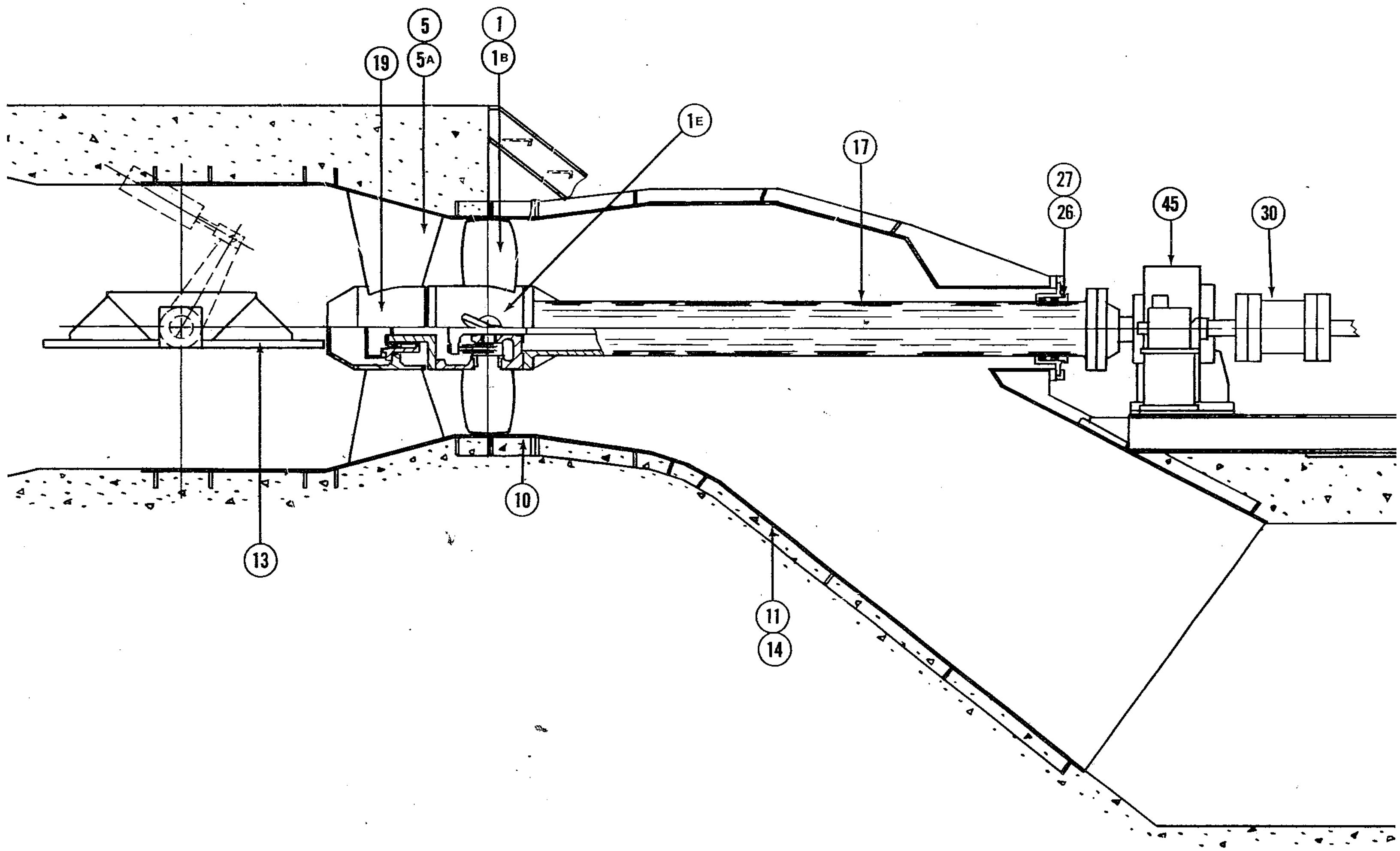
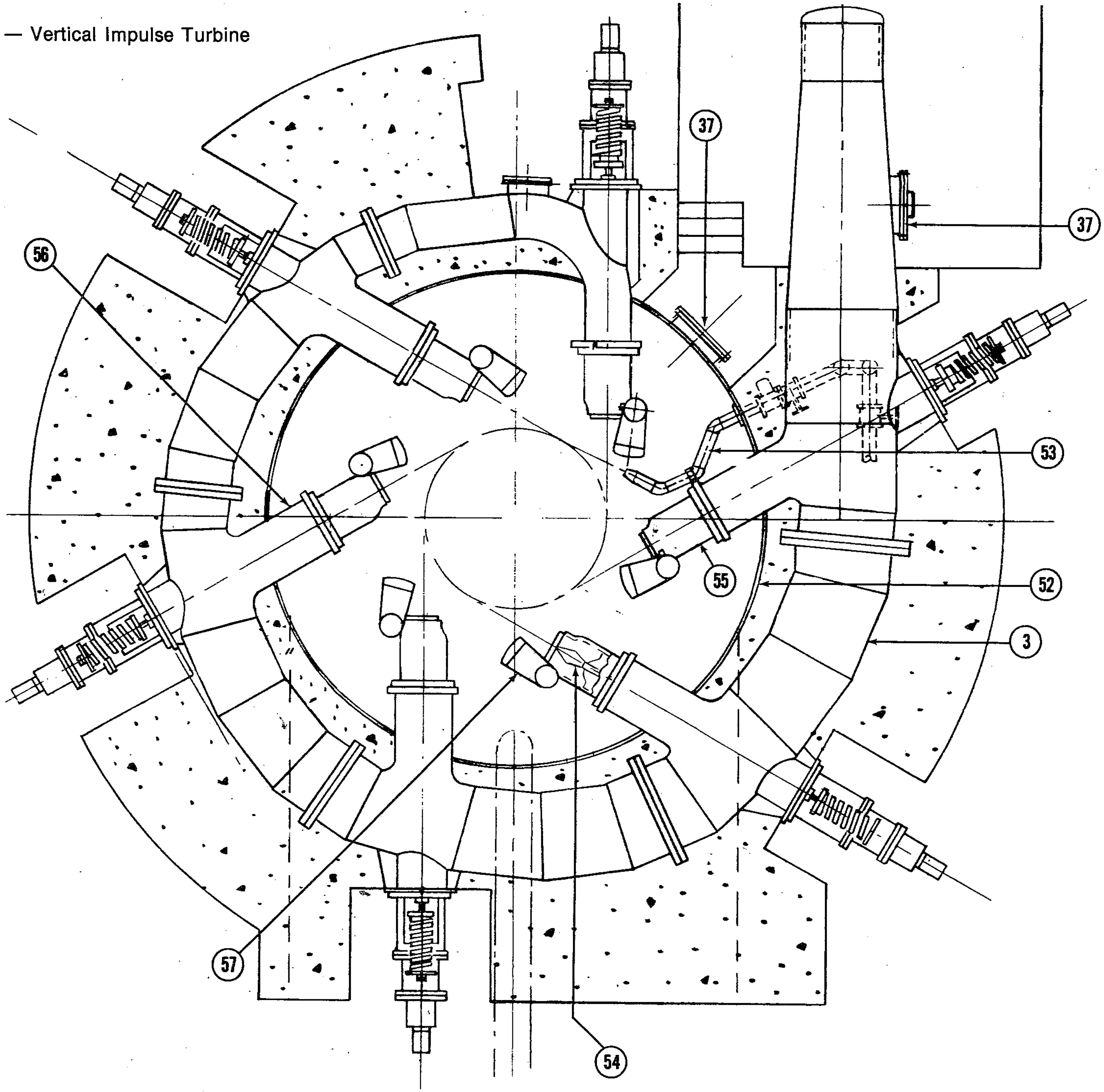


Fig. 5 — Standard TUBE Turbine

Fig. 6A — Vertical Impulse Turbine



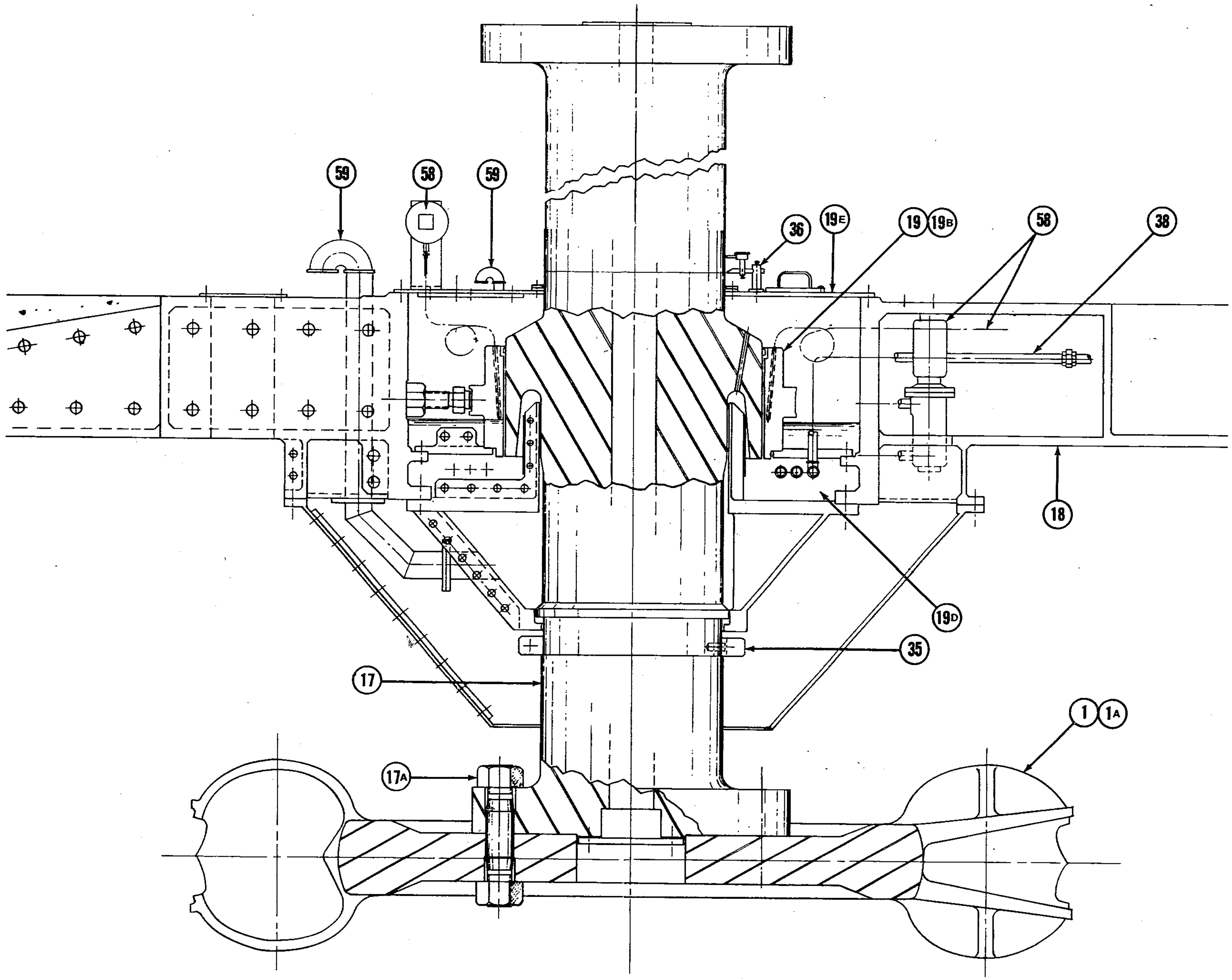


Fig. 6B — Vertical Impulse Turbine

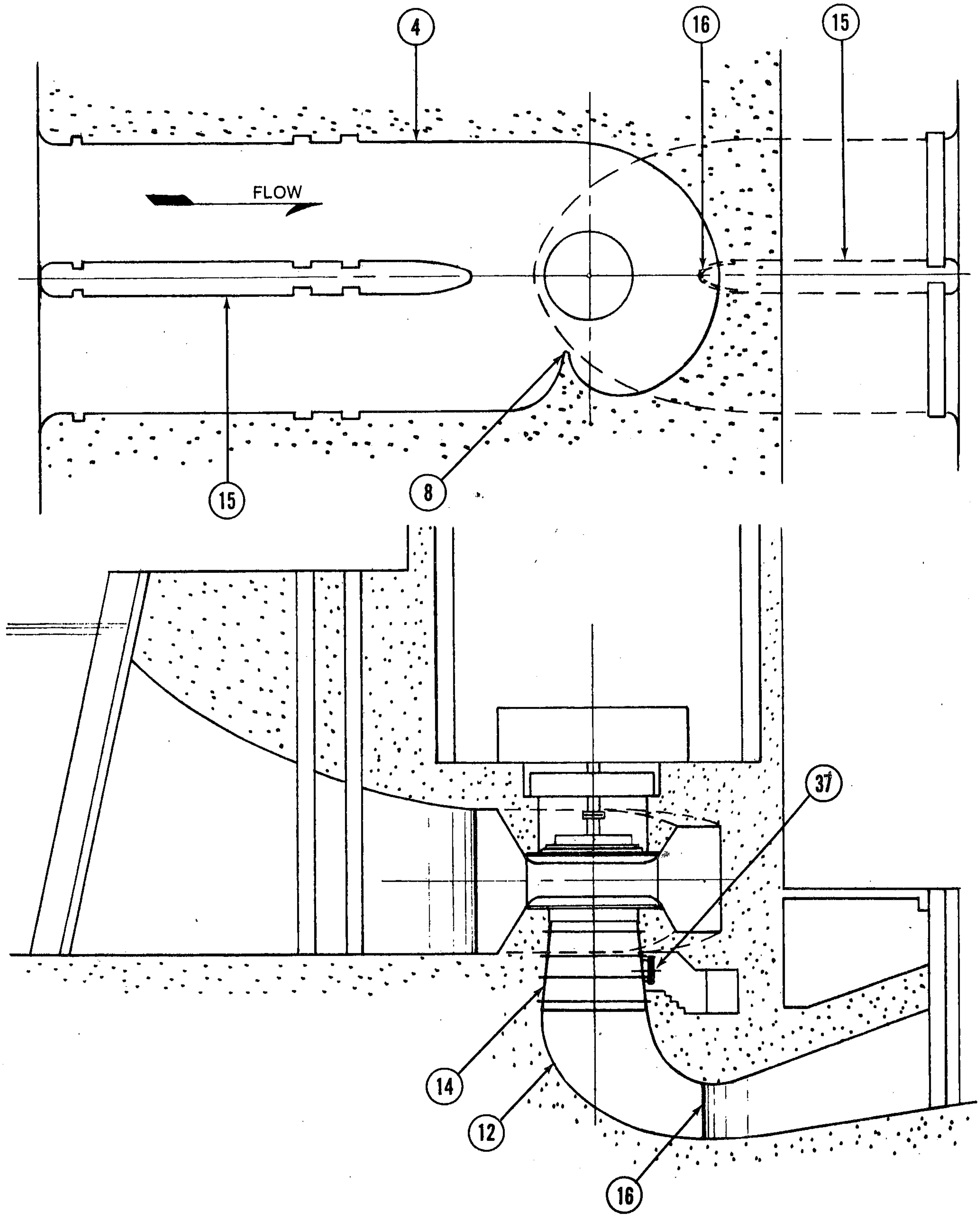


Fig. 7 — Concrete Semi-Spiral Case and Elbow Draft Tube

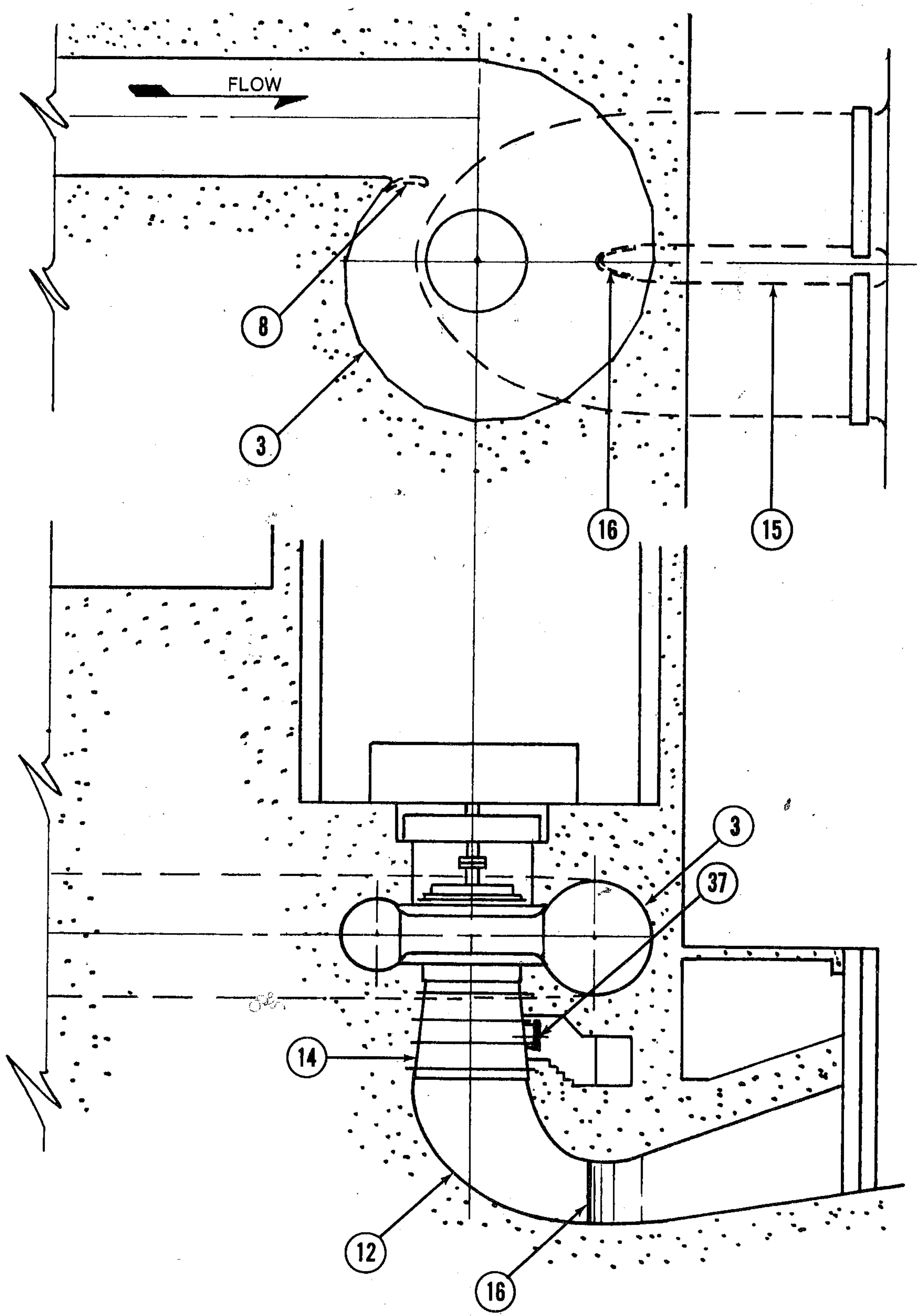


Fig. 8 — Plate Steel Spiral Case and Elbow Draft Tube

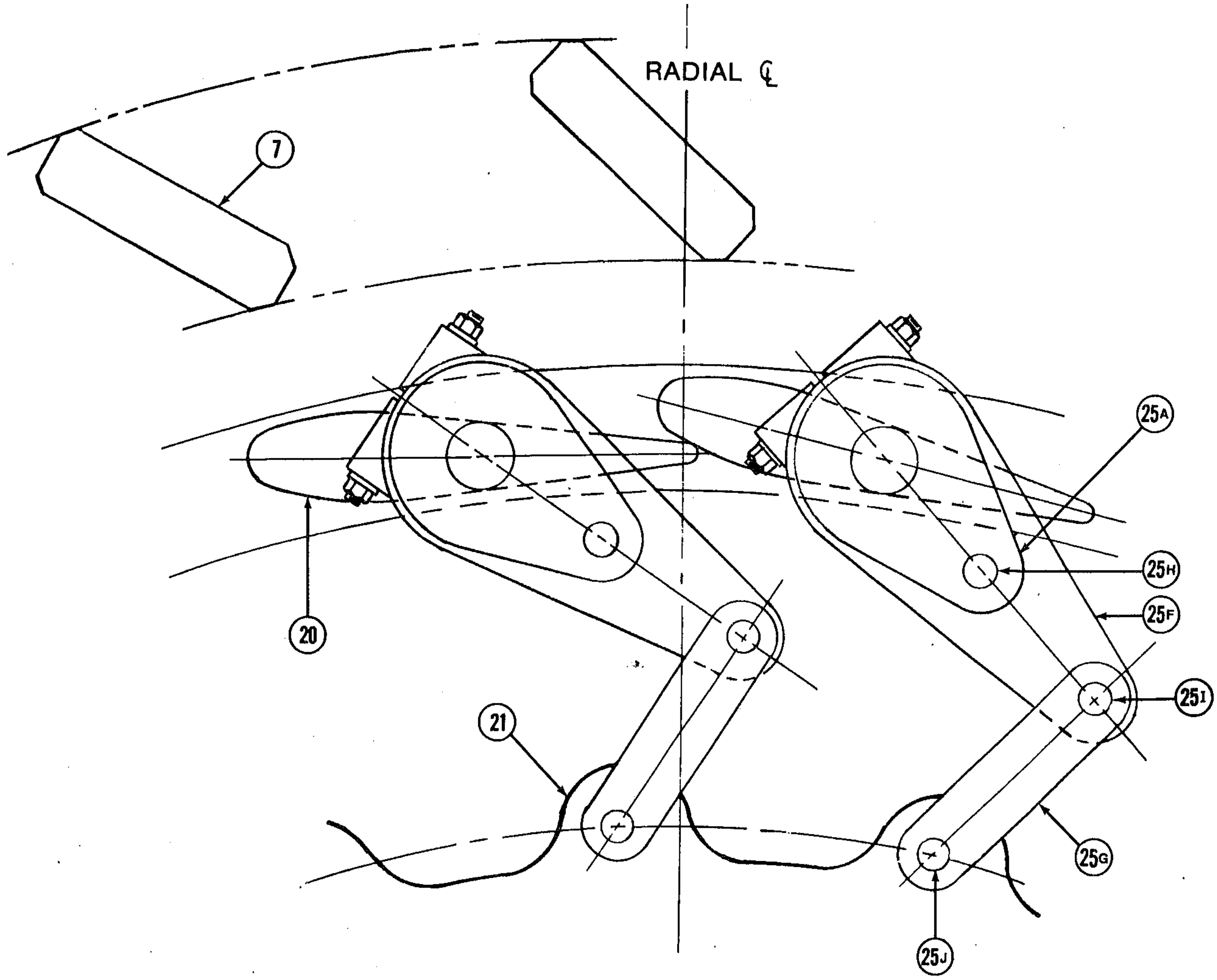


Fig. 9 — Wicket Gate Linkage (25)

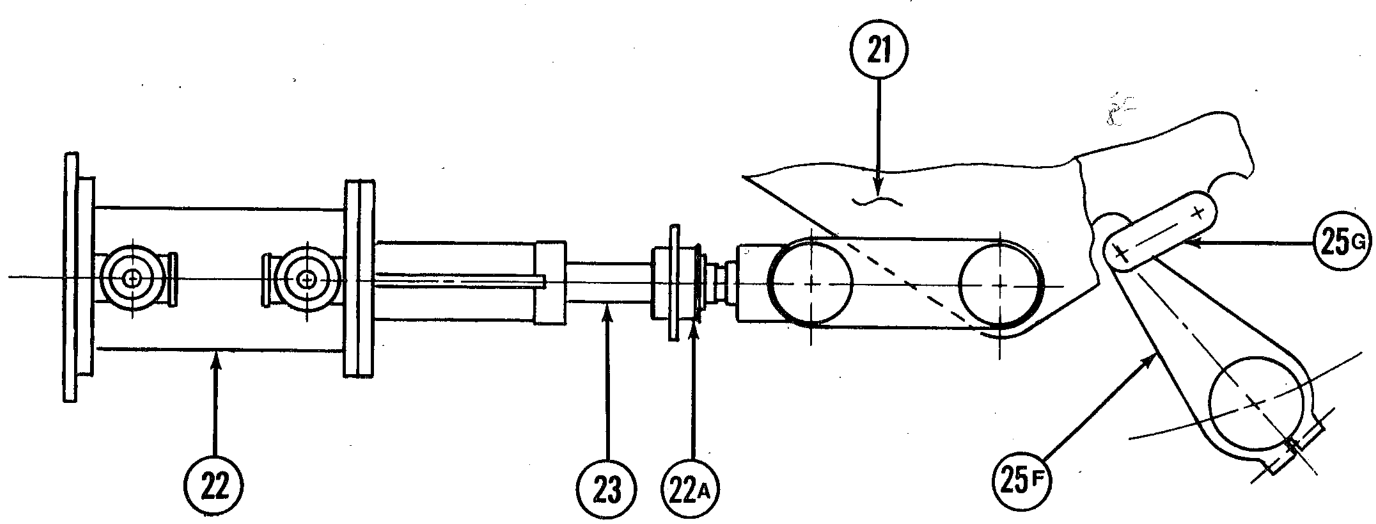


Fig. 10 — Wicket Gate Mechanism (24)

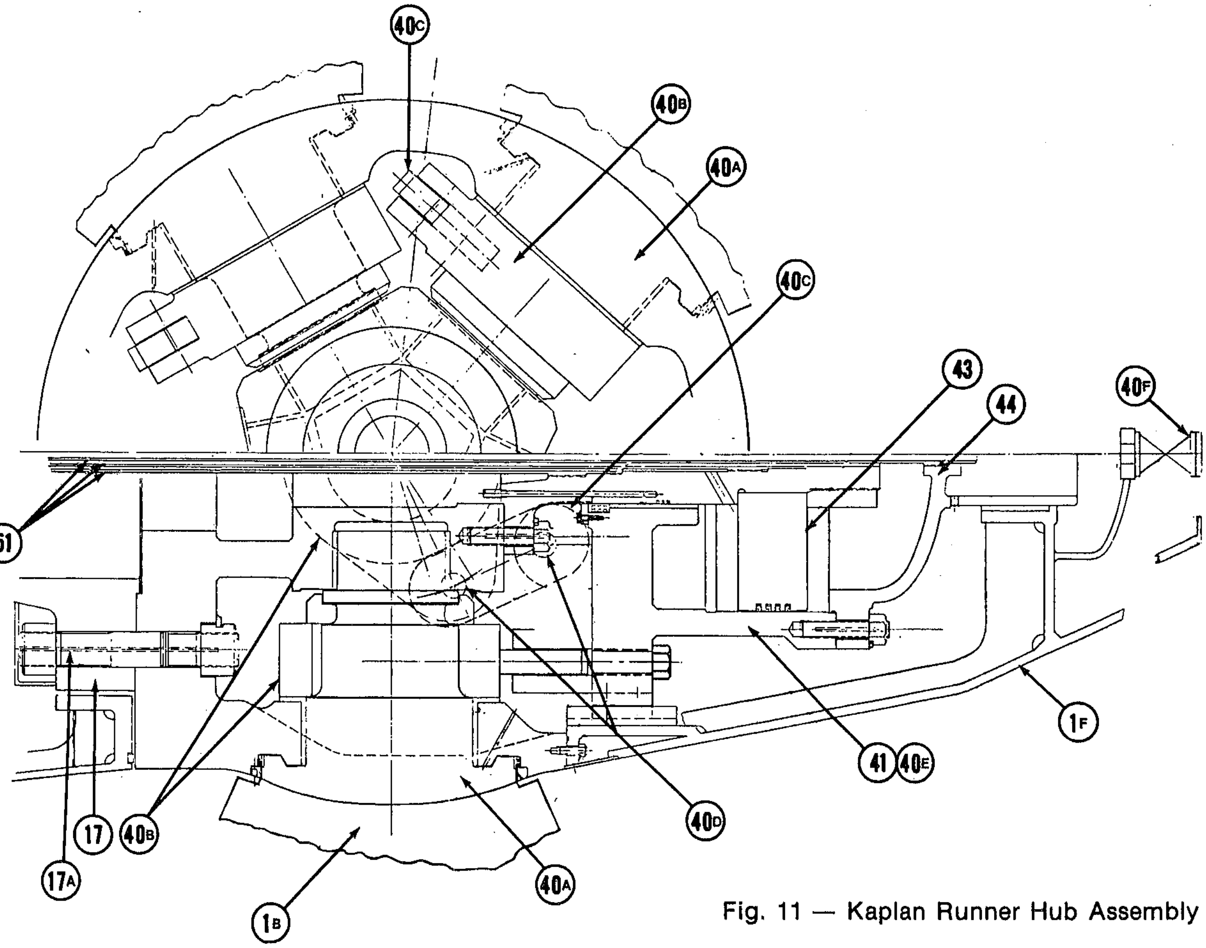


Fig. 11 — Kaplan Runner Hub Assembly

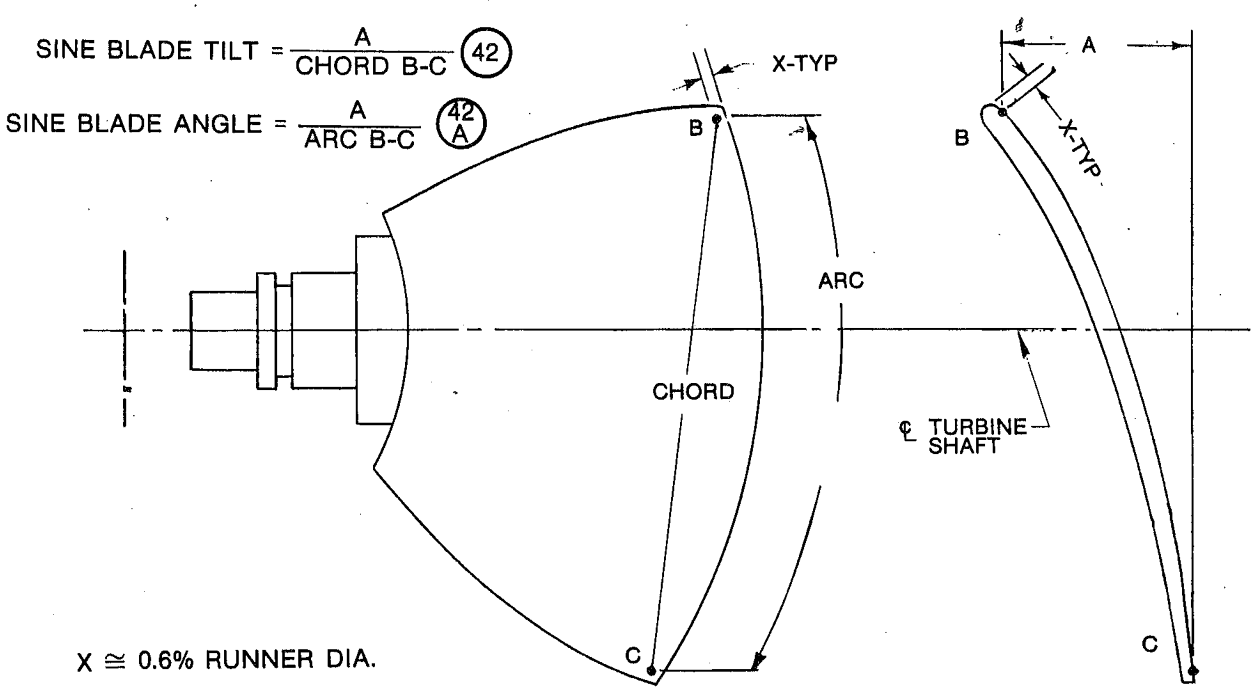


Fig. 12 — Kaplan Blade Tilt and Blade Angle

2.0 STANDARD DIMENSIONS, QUANTITIES AND DIMENSIONLESS PARAMETERS

2.1 Standard Dimensions

To clearly describe the standard relevant dimensions used for hydraulic turbines and pump/turbines, a description is provided for each listed dimensional notation as well as a pictorial representation on one or more of the accompanying sketches. The sketches represent the principal type of hydraulic turbines. Of particular importance is Dimension D, which is used as the reference diameter in the standard dimensionless parameters for all types of turbines.

NOTE

Each definition appears only one time — above the figure where it is first depicted. However, z_2 is defined at each figure in which it appears to clarify the use of "blades", "buckets" and "vanes".

ADJUSTABLE AND FIXED BLADE PROPELLER TURBINES (Figure 13)

$D = D_1$ = Reference diameter — largest diameter of the runner measured at the blade centerline.

A' = Vertical distance between the wetted surface of the bottom ring and the blade centerline.

D_4 = Diameter at the top of the draft tube.

D_N = Largest diameter of the runner hub.

D_s = Diameter of the discharge ring at the blade centerline.

D_{ta} = Outside diameter of the stay vanes.

D_{ti} = Inside diameter of the stay vanes.

D_z = Gate pin circle — diameter at which the wicket gate stems are located.

H_{sp} = Distance between the top and the bottom of the semi-spiral case at the first section.

b_o = Water passage height at the wicket gates.

b_t = Water passage height through the stay ring.

h = Distance between the top of the semi-spiral case and the higher wetted surface of the stay ring at any radial section.

h' = Distance between the bottom of the semi-spiral case and the lower wetted surface of the stay ring at any radial section.

s_r = Radial clearance between the runner blades and the discharge ring at runner centerline elevation.

z_0 = Number of wicket gates.

z_2 = Number of runner blades.

z_t = Number of stay vanes.

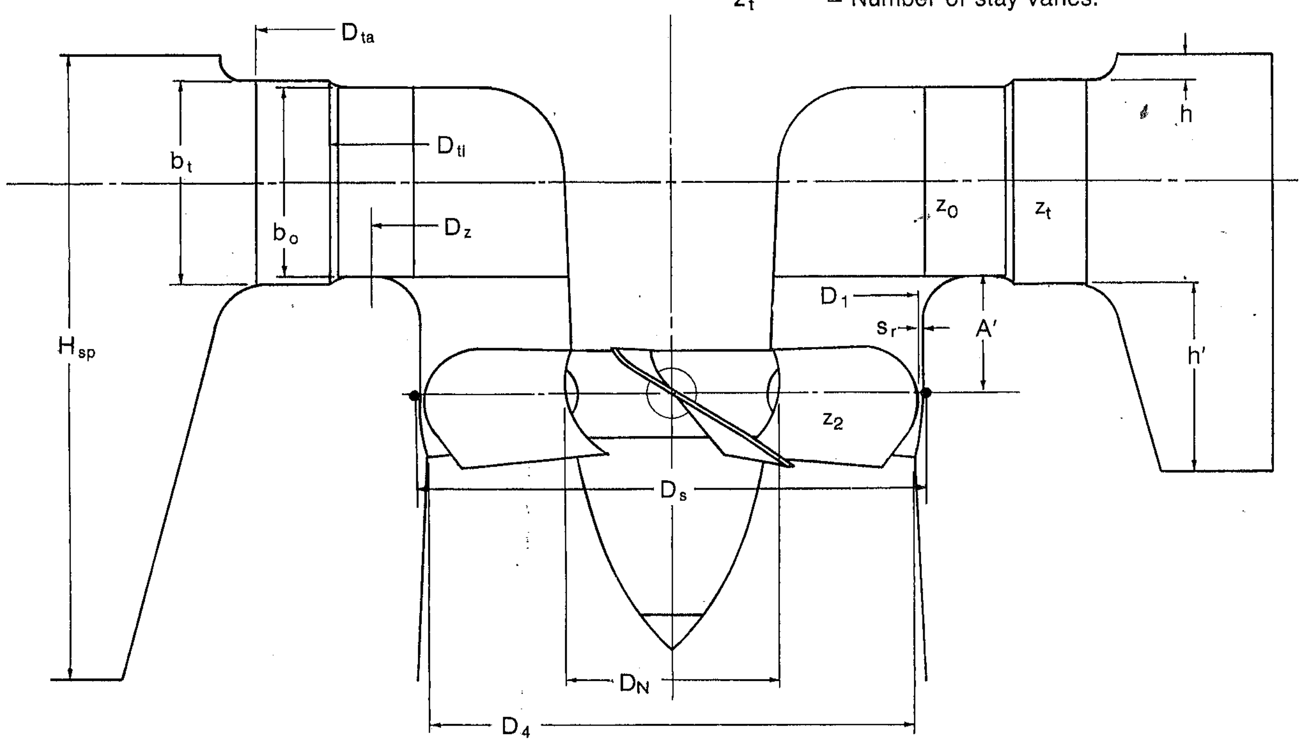


Fig. 13 — Kaplan or Fixed Blade Propeller Turbine

FRANCIS TURBINE (Figure 14)

$D = D_{1a}$ = Reference diameter at the intersection of the entrance (leading) edge of the runner buckets and the runner band.

D_1 = Runner diameter at distributor centerline elevation.

D_{1i} = Diameter at the intersection of the entrance edge of the runner buckets and the runner crown.

D_{2a} = Diameter at the intersection of the discharge edge of the runner buckets and the runner band.

D_{2i} = Diameter at the intersection of the discharge edge of the runner buckets and the runner crown.

D_3 = Runner discharge diameter.

D_B = Runner crown seal diameter.

D_H = Runner throat diameter (minimum band diameter).

D_K = Runner band seal diameter.

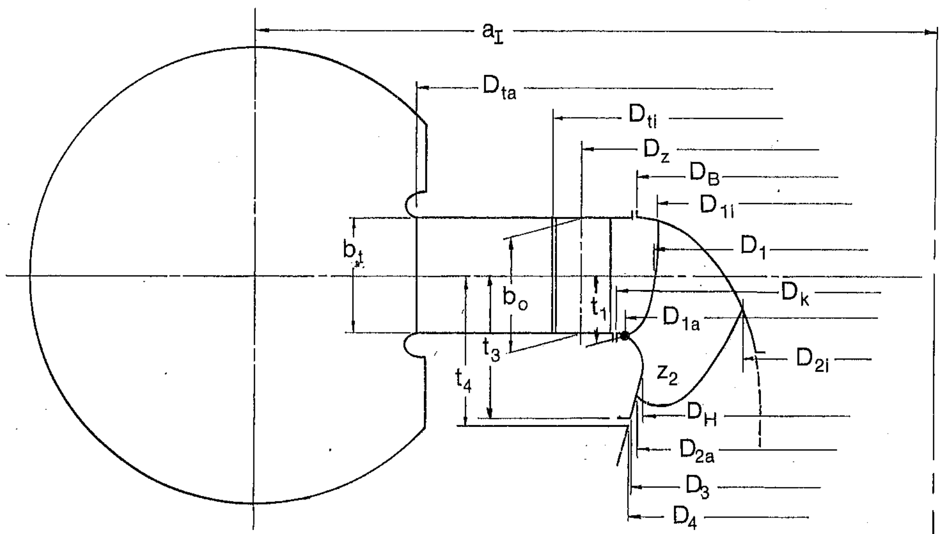
a_I = Distance from unit centerline to the center of the spiral case at Section I.

t_1 = Vertical distance from distributor centerline to the intersection of the leading edge of the runner buckets and runner band.

t_3 = Distance from the distributor centerline to the bottom of the runner.

t_4 = Distance from the distributor centerline to the top of the draft tube.

z_2 = Number of runner buckets.



FRANCIS TURBINE FIG. 14

FRANCIS REVERSIBLE PUMP/TURBINE (Figure 15)

$D = D_2$ = Reference diameter — Diameter of the pump discharge edge of the impeller vanes.

D_0 = Diameter at the top of the draft tube.

D_{1a} = Diameter at the intersection of the pump entrance edge of the impeller vanes and the band.

b_2 = Height of the impeller water passageway at the pump discharge.

b_4 = Water passage height at the wicket gates.

t_o = Distance from the distributor centerline to the top of the draft tube.

z_2 = Number of impeller vanes.

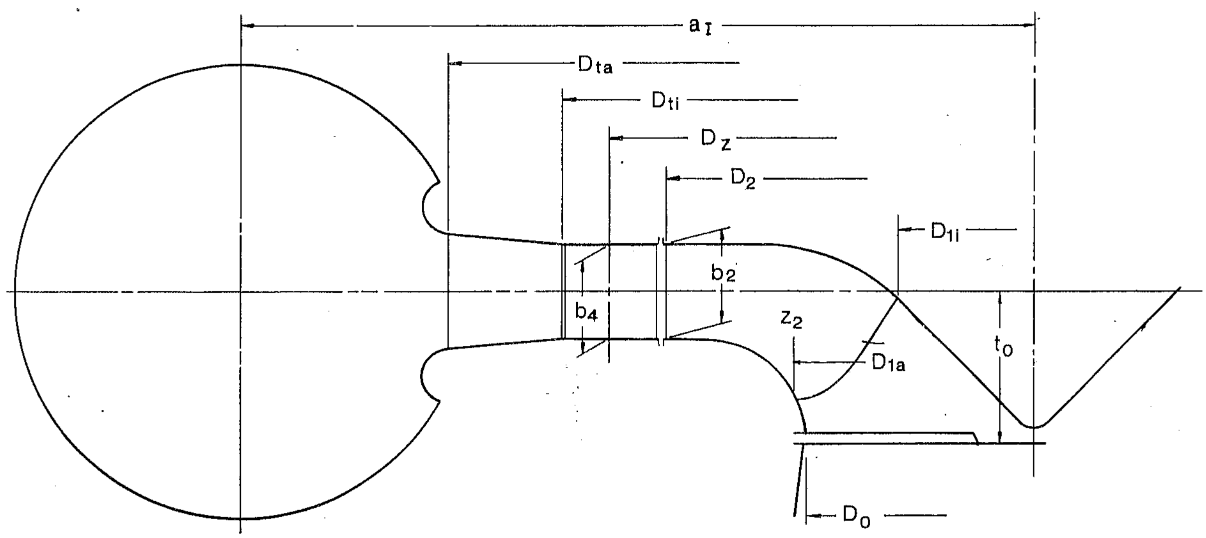


Fig. 15 — Francis Reversible Pump/Turbine

TUBE AND BULB TURBINE (Figures 16 and 17)

$D = D_1$ = Reference diameter — Largest diameter of the runner measured at the blade centerline.

B_o = Width of the intake section.

B_s = Width of the discharge section.

D_b = Bulb diameter.

H_o = Height of the intake section.

H_s = Height of the discharge section.

L_b = Distance from the bulb nose to the runner blade centerline.

L_s = Distance from the runner/impeller centerline to the center of the draft tube discharge section.

Θ = Angle between the main shaft centerline and a horizontal plane.

α = Angle between the wicket gate centerline and the main shaft centerline.

z_2 = Number of runner blades.

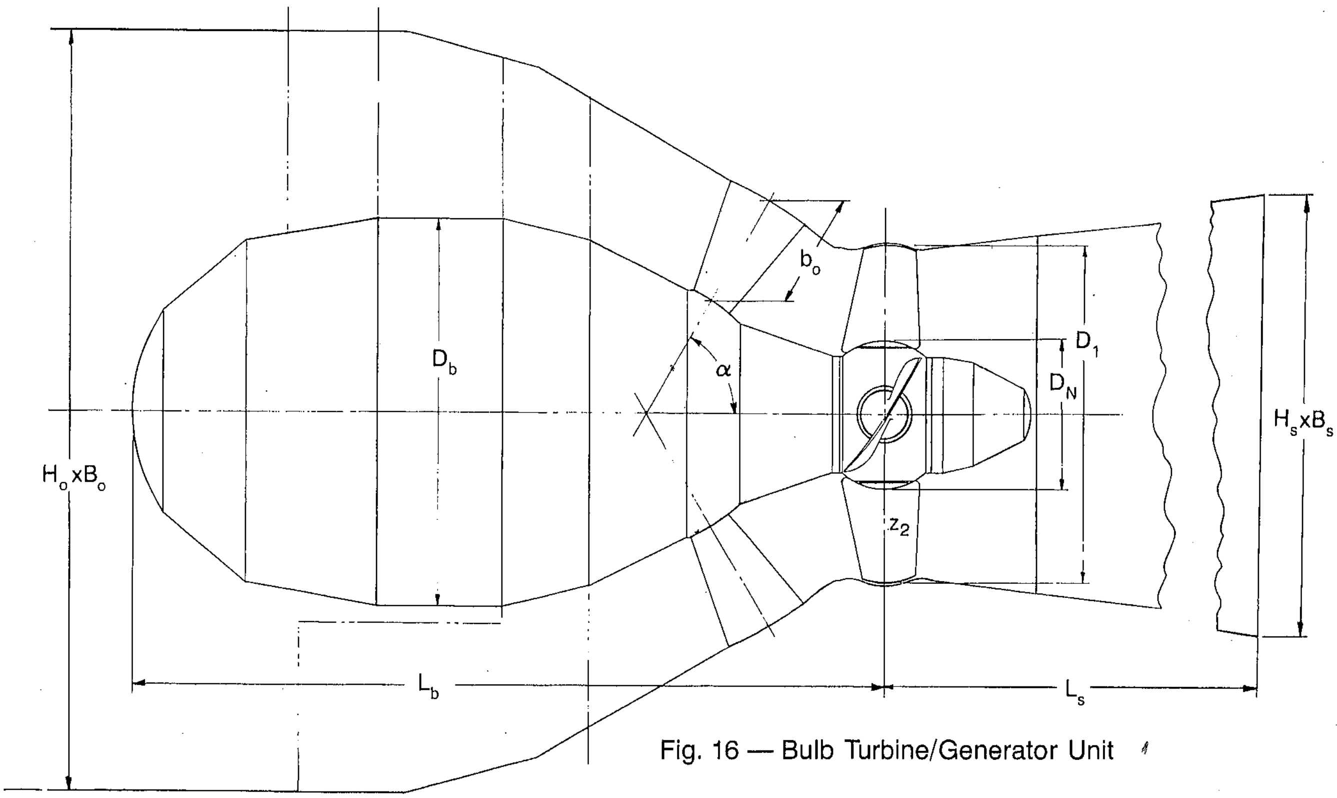


Fig. 16 — Bulb Turbine/Generator Unit

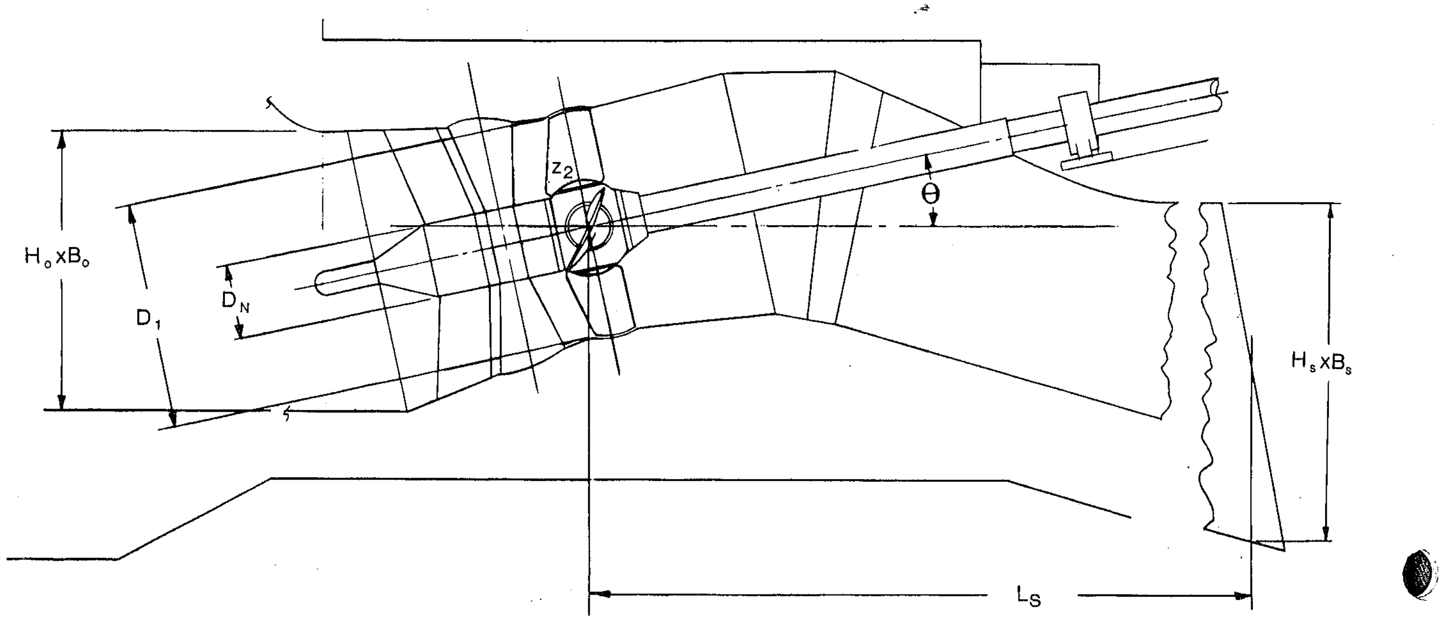


Fig. 17 — TUBE Turbine

IMPULSE TURBINE (Figures 18 and 19)

$D = D_1$ = Reference diameter = pitch diameter of the runner.
D_a = Outer diameter of the runner.
D_d = Penstock diameter.
D_n = Inlet diameter of nozzle.
b = Width of runner bucket.

d = Nozzle orifice diameter.
d_o = Full needle opening jet diameter.
z_o = Number of nozzles.
z_2 = Number of buckets.
φ = Angle between nozzle centerlines.

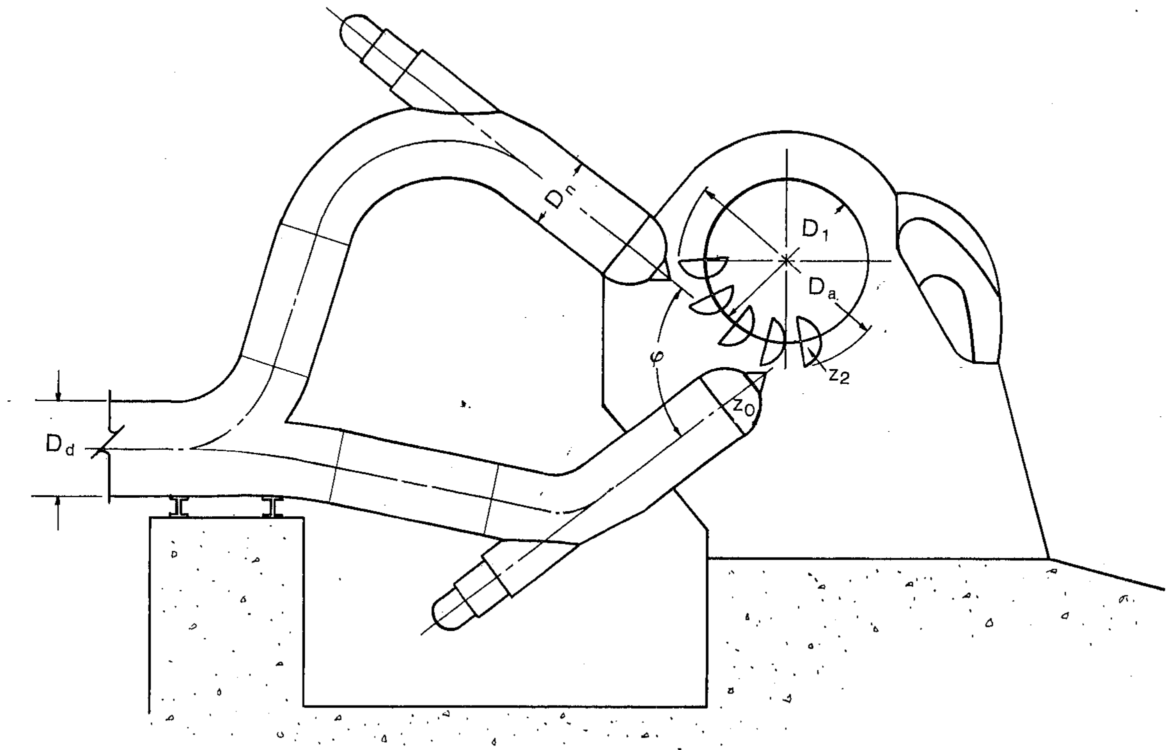
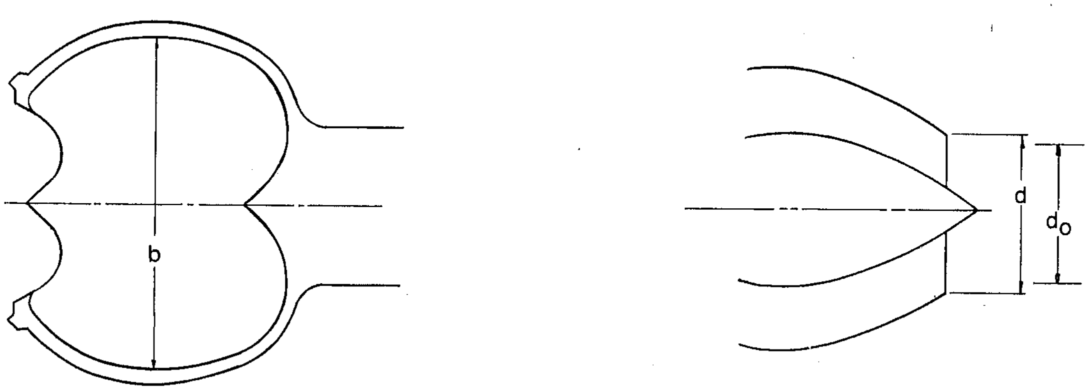


Fig. 18 — Impulse Turbine



BUCKET

NOZZLE

Fig. 19 — Impulse Turbine

SPIRAL CASE AND SEMI-SPIRAL CASE (Figures 20 and 21)

I II = Reference centerline. The plane through the centerline of the unit perpendicular to the spiral case (or semi-spiral case) inlet section. Looking upstream, the numeral I is always to the right.

B_d = Semi-spiral case inlet width.

B_{sp} = Largest distance across a spiral case.

D_d = Spiral case inlet diameter.

D_{sp} = Spiral case throat diameter.

H_d = Semi-spiral case inlet height.

L_d = Distance between the spiral case inlet and the I - II centerline.

L_{sp} = Distance from the I - II centerline to the throat.

R = Distance from the center of the unit to the outside diameter of the spiral case.

R_I = Radial distance from the center of the unit to the outer wetted surface of the spiral case at 180° from R_{II}.

R_{II} = Radial distance from the center of the unit to the largest section of the spiral case measured on the I - II centerline.

R_{III} = Same as R_I except at 90° from R_{II}.

R_{IV} = Same as R_I except at 270° from R_{II}.

a_d = Distance from the unit centerline to the center of the case inlet.

a_{sp} = Distance from the unit centerline to the centerline of the throat.

φ' = Nose vane angle from I - II centerline.

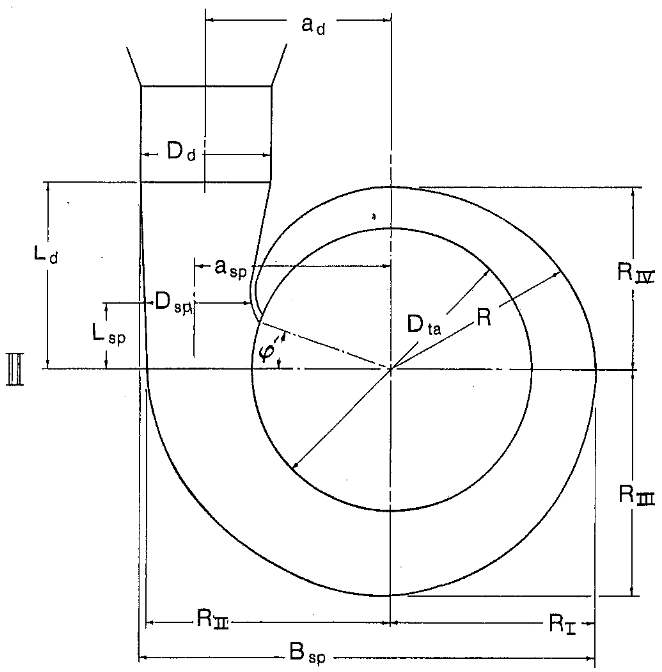


Fig. 20 — Spiral Case

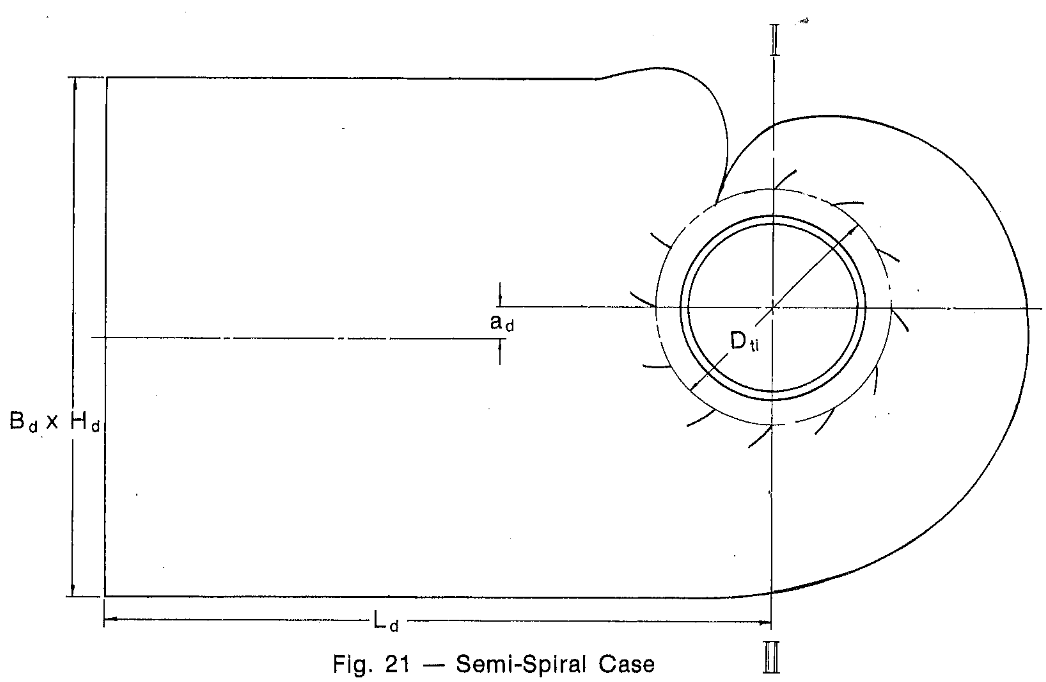


Fig. 21 — Semi-Spiral Case

DRAFT TUBE (Figure 22)

D_4 = Diameter at the top of the draft tube.

D_5 = Largest diameter of the draft cone.

L_s = Horizontal distance from the unit centerline to the discharge section.

T = Vertical distance from the distributor centerline to the bottom of the draft tube.

T_4 = Vertical distance from the top of the draft tube to the bottom of the draft tube.

T_5 = Vertical distance from the plane across the largest diameter of the draft cone to the bottom of the draft tube.

T_c = Vertical distance from the runner blade centerline to the bottom of the draft tube.

t_5 = Vertical distance from the plane at the largest diameter of the draft cone to the distributor centerline.

t_c = Vertical distance from the runner blade centerline to the distributor centerline.

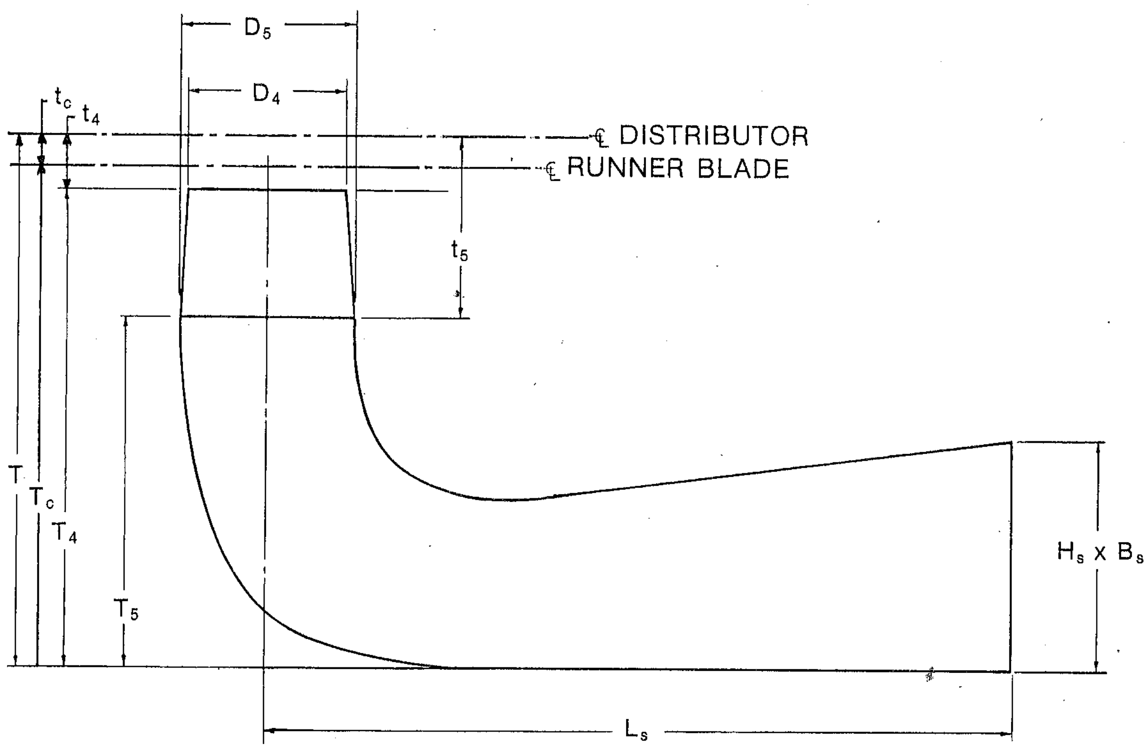


Fig. 22 — Elbow Draft Tube

2.2 Standard Hydraulic Quantities

The fundamental quantities that are used to describe the principal hydraulic conditions in a turbine are listed along with the standard symbols and the units of measure. These standard notations are used for the standard dimensionless parameters in Section 2.3.

2.2.1 HYDRAULIC NOTATIONS AND DESCRIPTIONS

SYMBOL	FUNDAMENTAL QUANTITY	UNIT
A	Cross-sectional area	m^2 or mm^2
a	Gate opening	mm
b	Water passage height	mm
D	Reference diameter for the machine	mm
D_z	Diameter of gate pin circle	mm
F_A	Axial force	N
F_R	Radial force	N
g	Acceleration due to gravity	m/s^2
gH	Specific energy (Energy per unit mass)	m^2/s^2
H	Head difference between inlet and outlet sections	m
H_L	Head loss	m
h_a	Absolute pressure head	m
h_p	Pressure head ($p/\rho g$)	m
h_s	Geodetic suction head	m
h_t	Total head (h_p+h_v+z)	m
h_v	Velocity head ($v^2/2g$)	m
h_{va}	Vapor pressure head	m
n	Rotational speed ($30\omega/\pi$)	rev/min
η	Efficiency - for turbine $\eta = P/\rho gQH$ for pump $\eta = \rho gQH/P$	%
NPSH	Net positive suction head	m
P	Shaft power ($T \bullet \omega$)	W
p	Pressure	Pa
Q	Flow or discharge	m^3/s
s	Time	seconds
T	Torque	Nm
T_B	Blade torque (due to hydraulic loads)	Nm
T_G	Wicket gate torque (due to hydraulic loads)	Nm
TDH	Total dynamic head - difference between total heads at pump inlet and outlet sections	m
μ	Dynamic viscosity	Pa•s
v	Fluid velocity (Q/A)	m/s
ω	Angular velocity	rad/sec
z	Geodetic head	m
β	Blade tilt	degrees
γ	Specific weight (ρg)	N/m^3
ρ	Mass density	kg/m^3

2.3 Dimensionless Parameters

The listed parameters and coefficients greatly enhance the capability to analyze, evaluate and predict performance of hydraulic turbines and pump/turbines. Their usage is discussed in Section 3.0.

PARAMETER	DESIGNATION	DEFINITION
Unit Speed	ω_{ed}	$\frac{\omega D}{(gH)^{0.5}}$
Unit Discharge	Q_{ed}	$\frac{Q}{D^2 (gH)^{0.5}}$
Unit Torque	T_{ed}	$\frac{T}{\rho D^3 gH}$
Unit Power	P_{ed}	$\frac{P}{\rho D^2 (gH)^{1.5}}$
Energy Coefficient	$E_{\omega d}$	$\frac{gH}{(\omega D)^2}$
Discharge Coefficient	$Q_{\omega d}$	$\frac{Q}{\omega D^3}$
Torque Coefficient	$T_{\omega d}$	$\frac{T}{\rho \omega^2 D^5}$
Power Coefficient	$P_{\omega d}$	$\frac{P}{\rho \omega^3 D^5}$
Specific Speed	ω_s	$\frac{\omega Q^{0.5}}{(gH)^{0.75}}$
Cavitation Coefficient*	σ	$\frac{h_b - h_{va} - h_s}{H}$

*If a long water passageway exists between tailwater and draft tube inlet or outlet, the head loss H_L must be considered in evaluating cavitation coefficient σ.

3.0 MODEL TESTS

3.1 Turbine Operation

Turbine model testing is conducted to obtain performance data of the machine for predicting prototype characteristics. The principal quantities measured are flow (Q), total pressure at the turbine spiral case inlet expressed in meters of head, total pressure at the discharge of the draft tube expressed in meters of head, shaft speed, and shaft torque. These quantities are recorded at constant gate opening (a) and blade tilt (β) (for adjustable blade turbines).

The above quantities are combined to yield output power (P), differential head across the machine (H) and efficiency (η). The data is translated to standard conditions from the actual test conditions by correcting the mass density (ρ) and the acceleration due to gravity (g) to standard values.

The above performance quantities at standard conditions are further combined to produce performance maps in the form of hill curves using the following dimensionless coefficients:

$Q_{\omega d}$ — discharge coefficient
$P_{\omega d}$ — power coefficient
η — efficiency (%)
$E_{\omega d}$ — energy coefficient

A typical representation in this form is shown in Figure 23. Lines of constant power coefficient ($P_{\omega d}$) and gate opening (a) are plotted on the performance map along with constant efficiency contours. The presentation of data in this form facilitates conversion to prototype size and speed. The energy coefficient ($E_{\omega d}$) is directly proportional to net head for a given prototype diameter and synchronous speed. Proportional relationships also exist between the prototype flow rate (Q) and power (P) and the dimensionless coefficients.

In general, the runaway speed characteristics for a turbine will be shown on a separate curve as a plot of energy coefficient ($E_{\omega d}$) versus cavitation coefficient (σ).

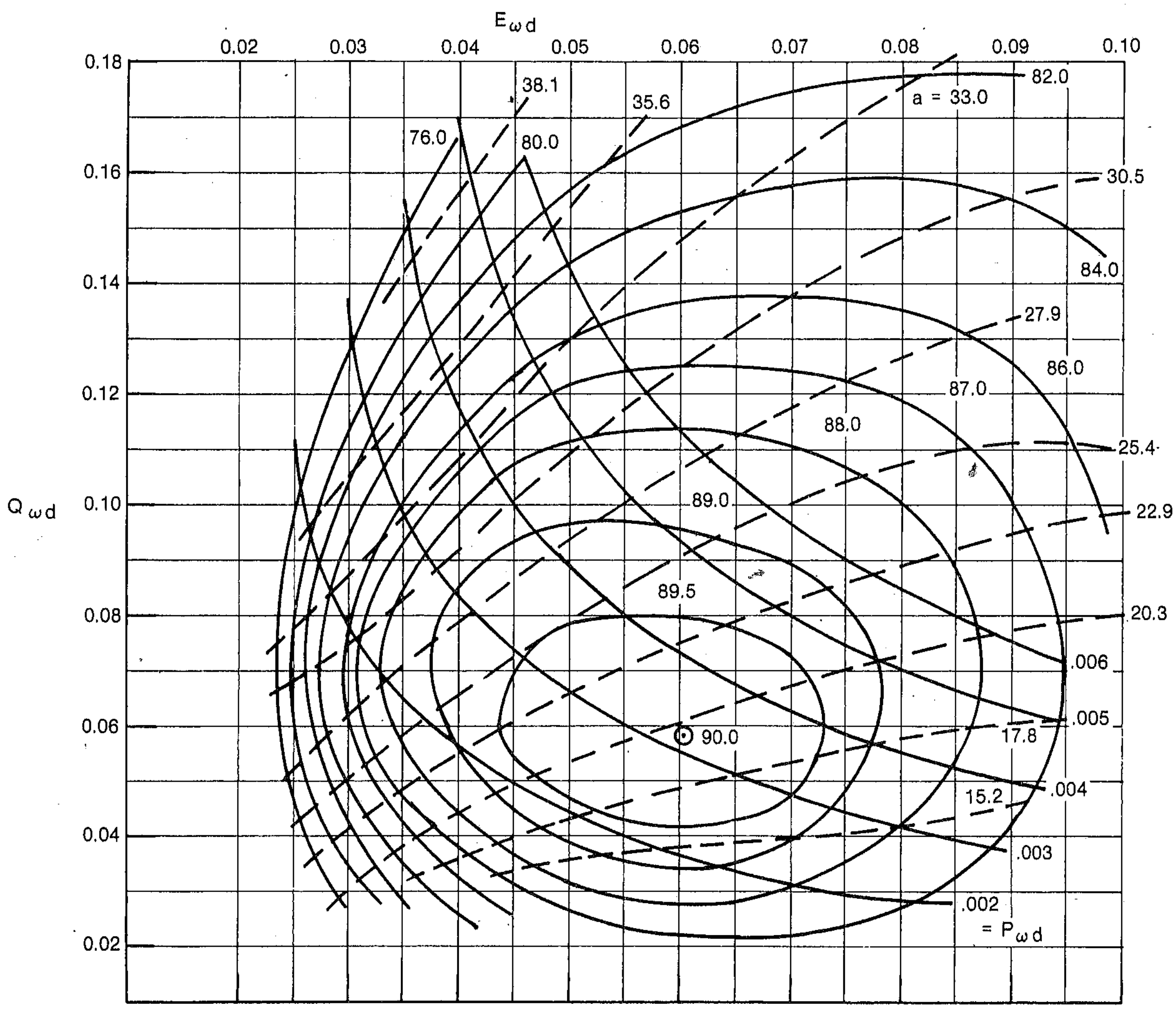


Fig. 23 — Typical Model Hill Curve — Turbine Operation

3.2 Pump Operation

Performance data measured for pump operation are similar to those obtained for turbine operation except that the spiral case inlet section is the reference pump discharge section and the draft tube exit is the reference pump inlet section. The principal quantities measured are pump head (H), flow rate (Q), shaft power input (P) and rotational speed (n). These quantities are then combined to yield the same dimensionless coefficients, $Q_{\omega d}$, $E_{\omega d}$, $P_{\omega d}$, and η, used for characterizing turbine performance.

Model tests for pump operation are normally performed at constant gate openings. However, performance plots may only show the envelope of best operation for all gates tested. A typical plot is shown in Figure 24.

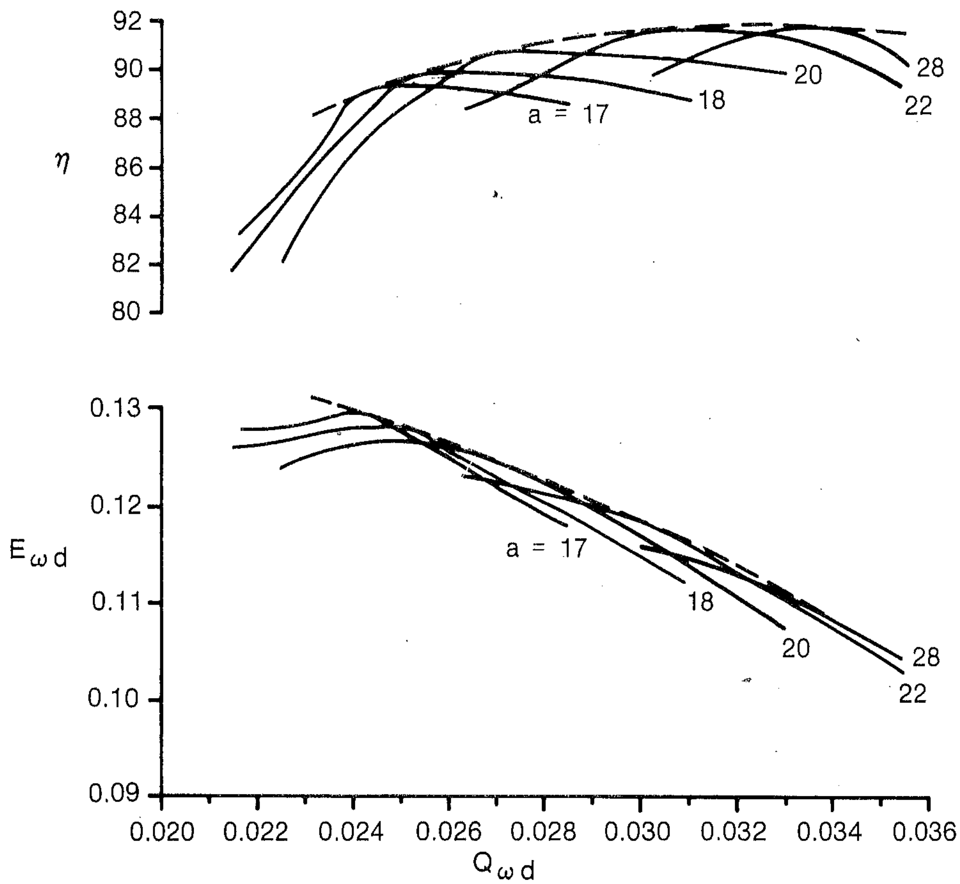


Fig. 24 — Typical Model Performance — Pump Operation

3.3 Operational Data

Operational data for turbines and pump/turbines is measured to obtain useful information for the optimum operation of the unit and its hydraulic system. This data is used specifically for estimating critical loads during transient operations of the prototype units. Because many of these significant measurements are dynamic signals, care must be taken in scaling the values to prototype equivalents.

Operational data for conventional turbines is normally limited to the "normal turbine operating range" (Zone 3 in Figure 25A) and the "reverse pump operating range" (Zone 4 in Figure 25A).

3.4 Four Quadrant Data

The four principal quantities measured for performance characteristics are normally measured as time-averaged quantities at a steady operating point. These measured quantities are shaft torque (T), flow rate (Q), shaft speed (n), and differential head across the machine (H). These quantities are reduced to dimensionless parameters called unit values:

1. Unit Speed — ω_{ed}
2. Unit Discharge — Q_{ed}
3. Unit Torque — T_{ed}

and plotted on curves as a function of gate opening (a). Figures 25A and B show representative plots of pump/turbine four quadrant characteristics

The sign conventions chosen for these plots are arbitrary. Unit speed (ω_{ed}) is positive for rotation in the normal turbine direction and negative in the pump direction. Unit discharge (Q_{ed}) is positive for flow in the normal turbine direction and negative in the normal pump direction. Unit torque (T_{ed}) is positive as applied for normal pump and normal turbine operation; negative otherwise.

In this way, power output (available to a driven machine) is positive for turbine operation turbining ($T^{(+)} \bullet \omega^{(+)} = P^{(+)}$) and negative pumping ($T^{(+)} \bullet \omega^{(-)} = P^{(-)}$).

Information from Figures 25A and 25B is used to estimate the transient characteristics of prototype units.

In Figure 25A the four quadrants may be identified as:

1. Normal pump operating range
2. Pump energy dissipation range
3. Normal turbine operating range
4. Turbine rotation — flow in pump direction

In Figure 25B quadrant 2 is normal pump operation and quadrant 3 is normal turbine operation.

3.5 Torque, Thrust and Dynamic Pressure

Increased capabilities of modern test facilities, combined with better instrumentation and data reduction techniques make it possible to measure many more characteristics of operation than has been common in the past. Wicket gate torque, blade torque, impeller/runner axial and radial thrusts, draft tube and priming chamber pressures are now regularly recorded during four quadrant testing. These data are used during prototype steady or transient simulations to estimate operating forces throughout the unit. They are reduced to dimensionless coefficients and presented as a function of unit speed (ω_{ed}) and wicket gate opening (a).

The coefficients may be time averaged (or D.C.) values or may be some representation of the dynamic signal (A.C. component).

For a broad look at model loads, software for measuring the steady and peak-to-peak alternating data is used. (The data signal is sampled at the maximum rate for N sample periods. For each of the

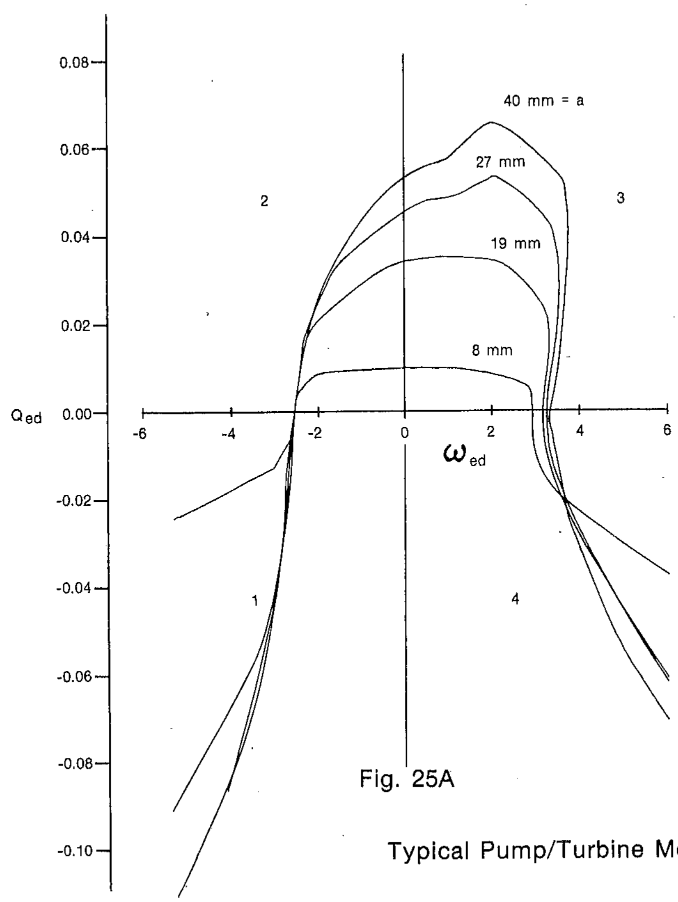


Fig. 25A

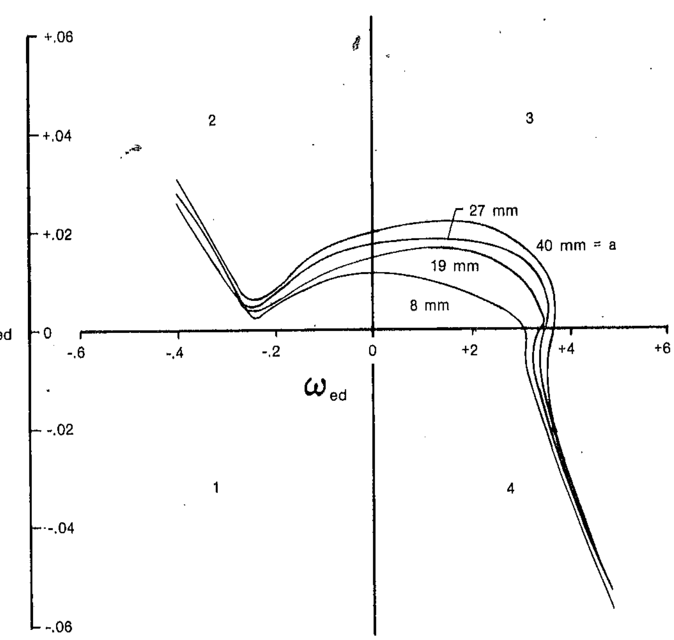


Fig. 25B

Typical Pump/Turbine Model Four Quadrant Characteristics

N sample periods, the maximum and minimum values of the signal are determined, and then the average maximum and minimum signal levels are computed over all N periods).

Utilizing the above, the average steady and average peak-to-peak dynamic data components are acquired. The average steady data is designated as k_G, k_B, k_A and k_R, while the average peak-to-peak dynamic data components are designated Δk_G, Δk_B, Δk_A, Δk_R and Δk_P.

a) Wicket gate torque coefficient - k_G
   $k_G = T_G / t_z^2 b\rho g H$
   $t_z = \dfrac{\pi D_z}{\text{number of wicket gates}}$

b) Blade torque coefficient - k_B
   $k_B = T_B / D^3\rho g H$

c) Axial thrust coefficent - k_A
   $k_A = 4F_A / \pi D^2\rho g H$

d) Radial thrust coefficient - k_R
   $k_R = F_R / Db\rho g H$

e) Dynamic pressure coefficient - Δk_P
   $\Delta k_P = \Delta h_P / H$

3.6 Cavitation

The cavitation factor sigma — σ (Thoma's coefficient) characterizes the setting of a hydraulic turbine or pump in relation to the discharge pool level or suction pool level respectively (Figure 26). The coefficient is a dimensionless number and it expresses the difference between the absolute outlet section (as a turbine) pressure head, referred to the elevation of a reference level on the runner, and the water vapor pressure head. The difference is then expressed in relation to the net head.

$$\sigma = \frac{h_b - h_{va} - h_s}{H}$$

h_b = Barometric pressure head.

h_s = Difference in elevation of the reference level on the runner to the discharge pool. As a convention, h_s has a positive value when the discharge pool is below the reference level on the runner as shown in Figure 26.

H = Head difference between inlet and outlet sections.

h_{va} = Vapor pressure head.

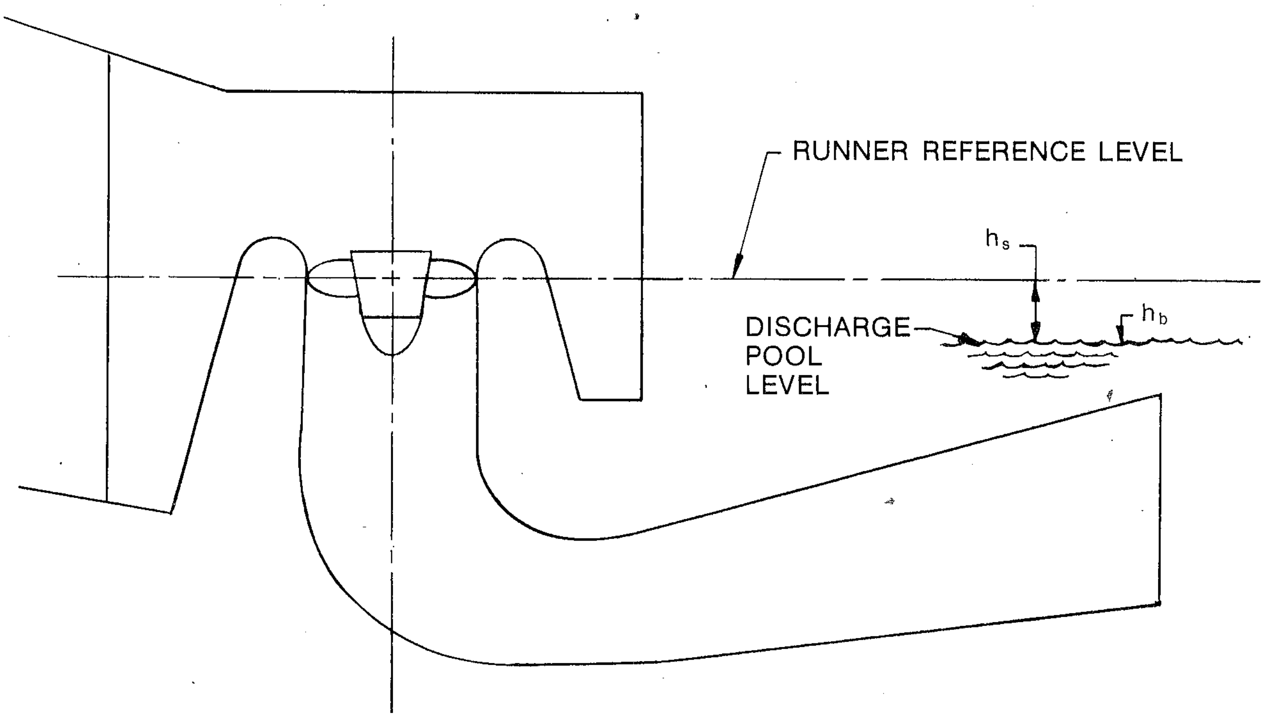


Fig. 26 — Turbine Setting Reference Dimensions

4.0 REFERENCE DATA

The various data included herein will be useful for analysis and evaluation of hydraulic machinery. Complete background information can be found in the following documents:

American National Standard — ANSI Z210.1-1976 — "ASTM/IEEE Standard Metric Practice."

International Standard ISO 1000 — "SI Units and Recommendations for the Use of Their Multiples and of Certain Other Units."

International Electrotechnical Commission Publication 497 — "International Code for Model Acceptance Tests of Storage Pumps."

4.1 Variation of Physical Quantities

Table 1 Density ρ of Dry Air

Air temperature °C	Barometric pressure h_b		
	100.0 kPa	101.3 kPa	103.0 kPa
	kg/m³	kg/m³	kg/m³
0	1.276	1.293	1.314
2	1.267	1.284	1.305
4	1.258	1.274	1.296
6	1.248	1.265	1.285
8	1.240	1.256	1.277
10	1.231	1.247	1.268
12	1.222	1.238	1.259
14	1.214	1.230	1.250
16	1.205	1.221	1.241
18	1.197	1.213	1.233
20	1.189	1.205	1.225
22	1.181	1.196	1.216
24	1.173	1.188	1.208
26	1.165	1.180	1.200
28	1.157	1.173	1.192
30	1.149	1.165	1.184

Source IEC 497

Table 2 Acceleration g Due to Gravity

Latitude ϕ degrees	Height z in meters above mean sea level			
	0 m/s²	1000 m/s²	2000 m/s²	4000 m/s²
0	9.780	9.777	9.774	9.768
10	9.782	9.779	9.776	9.770
20	9.786	9.783	9.780	9.774
30	9.793	9.790	9.787	9.781
40	9.802	9.799	9.796	9.789
50	9.811	9.808	9.804	9.798
60	9.819	9.816	9.813	9.807
70	9.826	9.823	9.820	9.814

The above table is derived from the formula:

$$g = 9.806\ 17(1-2.64\cdot10^{-3}\cos 2\phi+7\cdot10^{-6}\cos^2 2\phi) -3.086\cdot10^{-6}\cdot z$$

The international standard value of g is 9.806 65m/s².

Source IEC 497

Table 3 Variation with Temperature of the Density ρ and Vapor Pressure h_{va} of Distilled Water

Temperature °C	Density of Water kg/m³	Vapor Pressure		
		kPa	Bar	Meters of Water
0	999.87	0.611	0.00611	0.0623
1	999.93	0.657	0.00657	0.0670
2	999.97	0.705	0.00705	0.0719
3	999.99	0.758	0.00758	0.0772
4	1000.00	0.813	0.00813	0.0829
5	999.99	0.872	0.00872	0.0889
6	999.97	0.935	0.00935	0.0953
7	999.93	1.001	0.01001	0.1021
8	999.88	1.072	0.01072	0.1093
9	999.81	1.147	0.01147	0.1170
10	999.73	1.227	0.01227	0.1252
11	999.63	1.312	0.01312	0.1338
12	999.53	1.401	0.01401	0.1430
13	999.40	1.497	0.01497	0.1527
14	999.27	1.597	0.01597	0.1630
15	999.13	1.704	0.01704	0.1739
16	998.97	1.817	0.01817	0.1855
17	998.80	1.936	0.01936	0.1977
18	998.62	2.063	0.02063	0.2106
19	998.43	2.196	0.02196	0.2243
20	998.23	2.337	0.02337	0.2387
21	998.02	2.486	0.02486	0.2540
22	997.81	2.642	0.02642	0.2700
23	997.57	2.808	0.02808	0.2870
24	997.33	2.982	0.02982	0.3049
25	997.08	3.166	0.03166	0.3238
26	996.82	3.360	0.03360	0.3437
27	996.55	3.564	0.03564	0.3647
28	996.27	3.778	0.03778	0.3867
29	995.98	4.004	0.04004	0.4100
30	995.68	4.242	0.04242	0.4344
31	995.37	4.491	0.04491	0.4601
32	995.06	4.754	0.04754	0.0481
33	994.73	5.029	0.05029	0.5155
34	994.40	5.318	0.05318	0.5454
35	994.06	5.622	0.05622	0.5767

Source IEC 497

4.2 Alphabetical List of Conversion Factors

(Symbols for SI units are in parenthesis) This listing provides factors to convert from a variety of customary units used in the USA to standard SI units.

Conversion factors are written as a number greater than one and less than ten with six or less decimal places. The number is followed by the letter E, for exponent, a plus or minus sign, and two digits which indicate the power of ten by which the number must be multiplied to obtain the correct value.

To convert from	to	Multiply by
acre foot (US survey)	meter^3 (m^3)	1.233 489 E+03
acre (US survey)	meter^2 (m^2)	4.046 873 E+03
ampere hour	coulomb (C)	3.600 000 E+03
angstrom	meter (m)	1.000 000 E−10
astronomical unit	meter (m)	1.495 979 E+11
atmosphere (standard)	pascal (Pa)	1.013 250 E+05
atmosphere (technical = 1 kgf/cm^2)	pascal (Pa)	9.806 650 E+04
bar	pascal (Pa)	1.000 000 E+05
barrel (for petroleum, 42 gal)	meter^3 (m^3)	1.589 873 E−01
British thermal unit (International Table)	joule (J)	1.055 056 E+03
British thermal unit (mean)	joule (J)	1.055 87 E+03
British thermal unit (thermochemical)	joule (J)	1.054 350 E+03
British thermal unit (39° F)	joule (J)	1.059 67 E+03
British thermal unit (59°F)	joule (J)	1.054 80 E+03
British thermal unit (60°F)	joule (J)	1.054 68 E+03
Btu (International Table)•ft/h•ft^2•°F (*k*, thermal conductivity)	watt per meter kelvin (W/m•K)	1.730 735 E+00
Btu (thermochemical)•ft/h•ft^2•°F (*k*, thermal conductivity)	watt per meter kelvin (W/m•K)	1.729 577 E+00
Btu (International Table)/h	watt (W)	2.930 711 E−01
Btu (thermochemical)/h	watt (W)	2.928 751 E−01
Btu (International Table)/ft^2	joule per meter^2 (J/m^2)	1.135 653 E+04
Btu (thermochemical)/ft^2	joule per meter^2 (J/m^2)	1.134 893 E+04
Btu (thermochemical)/ft^2•min	watt per meter^2 (W/m^2)	1.891 489 E+02
Btu (International Table)/h•ft^2•°F (*C*, thermal conductance)	watt per meter^2 kelvin (W/m^2•K)	5.678 263 E+00
Btu (thermochemical)/h•ft^2•°F (*C*, thermal conductance)	watt per meter^2 kelvin (W/m^2•K)	5.674 466 E+00
Btu (International Table)/lb	joule per kilogram (J/kg)	2.326 000 E+03
Btu (thermochemical)/lb	joule per kilogram (J/kg)	2.324 444 E+03
Btu (International Table)/lb•°F (*c*, heat capacity)	joule per kilogram kelvin (J/kg•K)	4.186 800 E+03
Btu (thermochemical)/lb•°F (*c*, heat capacity)	joule per kilogram kelvin (J/kg•K)	4.184 000 E+03
calorie (International Table)	joule (J)	4.186 800 E+00
calorie (mean)	joule (J)	4.190 02 E+00
calorie (thermochemical)	joule (J)	4.184 000 E+00
calorie (15°C)	joule (J)	4.185 80 E+00
calorie (20°C)	joule (J)	4.181 90 E+00
calorie (kilogram, International Table)	joule (J)	4.186 800 E+03
calorie (kilogram, mean)	joule (J)	4.190 02 E+03
calorie (kilogram, thermochemical)	joule (J)	4.184 000 E+03

To convert from	to	Multiply by
cal (thermochemical)/cm²	joule per meter² (J/m²)	4.184 000 E+04
cal (International Table)/g	joule per kilogram (J/kg)	4.186 800 E+03
cal (thermochemical)/g	joule per kilogram (J/kg)	4.184 000 E+03
cal (International Table)/g•°C	joule per kilogram kelvin (J/kg•K)	4.186 800 E+03
cal (thermochemical)/g•°C	joule per kilogram kelvin (J/kg•K)	4.184 000 E+03
cal (thermochemical)/min	watt (W)	6.973 333 E−02
cal (thermochemical)/s	watt (W)	4.184 000 E+00
cal (thermochemical)/cm²•min	watt per meter² (W/m²)	6.973 333 E+02
cal (thermochemical)/cm²•s	watt per meter² (W/m²)	4.184 000 E+04
cal (thermochemical)/cm•s•°C	watt per meter kelvin (W/m•K)	4.184 000 E+02
centimeter of mercury (0°C)	pascal (Pa)	1.333 22 E+03
centimeter of water (4°C)	pascal (Pa)	9.806 38 E+01
centipoise	pascal second (Pa•s)	1.000 000 E−03
centistokes	meter² per second (m²/s)	1.000 000 E−06
circular mil	meter² (m²)	5.067 075 E−10
curie	becquerel (Bq)	3.700 000 E+10
day (mean solar)	second (s)	8.640 000 E+04
day (sidereal)	second (s)	8.616 409 E+04
degree (angle)	radian (rad)	1.745 329 E−02
degree Celsius	kelvin (K)	$t_K = t_{°C} + 273.15$
degree Fahrenheit	degree Celsius	$t_{°C} = (t_{°F} - 32)/1.8$
degree Fahrenheit	kelvin (K)	$t_K = (t_{°F} + 459.67)/1.8$
degree Rankine	kelvin (K)	$t_K = t_{°R}/1.8$
°F•h•ft²/Btu (International Table) (*R*, thermal resistance)	kelvin meter² per watt (K•m²/W)	1.761 102 E−01
°F•h•ft²/Btu (thermochemical) (*R*, thermal resistance)	kelvin meter² per watt (K•m²/W)	1.762 280 E−01
dyne	newton (N)	1.000 000 E−05
dyne•cm	newton meter (N•m)	1.000 000 E−07
dyne/cm²	pascal (Pa)	1.000 000 E−01
electronvolt	joule (J)	1.602 19 E−19
EMU of capacitance	farad (F)	1.000 000 E+09
EMU of current	ampere (A)	1.000 000 E+01
EMU of electric potential	volt (V)	1.000 000 E−08
EMU of inductance	henry (H)	1.000 000 E−09
EMU of resistance	ohm (Ω)	1.000 000 E−09
ESU of capacitance	farad (F)	1.112 650 E−12
ESU of current	ampere (A)	3.335 6 E−10
ESU of electric potential	volt (V)	2.997 9 E+02
ESU of inductance	henry (H)	8.987 554 E+11
ESU of resistance	ohm (Ω)	8.987 554 E+11
erg	joule (J)	1.000 000 E−07
erg/cm²•s	watt per meter² (W/m²)	1.000 000 E−03
erg/s	watt (W)	1.000 000 E−07
faraday (based on carbon-12)	coulomb (C)	9.648 70 E+04
faraday (chemical)	coulomb (C)	9.649 57 E+04
faraday (physical)	coulomb (C)	9.652 19 E+04
fermi (femtometer)	meter (m)	1.000 000 E−15
fluid ounce (US)	meter³ (m³)	2.957 353 E−05
foot	meter (m)	3.048 000 E−01
foot (US survey)	meter (m)	3.048 006 E−01
foot of water (39.2°F)	pascal (Pa)	2.988 98 E+03
ft²	meter² (m²)	9.290 304 E−02
ft²/h (thermal diffusivity)	meter² per second (m²/s)	2.580 640 E−05
ft²/s	meter² per second (m²/s)	9.290 304 E−02

To convert from	to	Multiply by
ft^3 (volume; section modulus)	meter^3 (m^3)	2.831 685 E−02
ft^3/min	meter^3 per second (m^3/s)	4.719 474 E−04
ft^3/s	meter^3 per second (m^3/s)	2.831 685 E−02
ft^4(moment of section)	meter^4 (m^4)	8.630 975 E−03
ft/h	meter per second (m/s)	8.466 667 E−05
ft/min	meter per second (m/s)	5.080 000 E−03
ft/s	meter per second (m/s)	3.048 000 E−01
ft/s^2	meter per second^2 (m/s^2)	3.048 000 E−01
footlambert	candela per meter^2 (cd/m^2)	3.426 259 E+00
ft•lbf	joule (J)	1.355 818 E+00
ft•lbf/h	watt (W)	3.766 161 E−04
ft•lbf/min	watt (W)	2.259 697 E−02
ft•lbf/s	watt (W)	1.355 818 E+00
ft•poundal	joule (J)	4.214 011 E−02
free fall, standard (*g*)	meter per second^2 (m/s^2)	9.806 650 E+00
gallon (Canadian liquid)	meter^3 (m^3)	4.546 090 E−03
gallon (UK liquid)	meter^3 (m^3)	4.546 092 E−03
gallon (US liquid)	meter^3 (m^3)	3.785 412 E−03
gal (US liquid)/day	meter^3 per second (m^3/s)	4.381 264 E−08
gal (US liquid)/min	meter^3 per second (m^3/s)	6.309 020 E−05
gal (US liquid)/hp•h (SFC, specific fuel consumption)	meter^3 per joule (m^3/J)	1.410 089 E−09
gamma	tesla (T)	1.000 000 E−09
gauss	tesla (T)	1.000 000 E−04
gilbert	ampere (A)	7.957 747 E−01
grad	degree (angular)	9.000 000 E−01
grad	radian (rad)	1.570 796 E−02
gram	kilogram (kg)	1.000 000 E−03
g/cm^3	kilogram per meter^3 (kg/m^3)	1.000 000 E+03
gram-force/cm^2	pascal (Pa)	9.806 650 E+01
hectare	meter^2 (m^2)	1.000 000 E+04
horsepower (550 ft•lbf/s)	watt (W)	7.456 999 E+02
horsepower (boiler)	watt (W)	9.809 50 E+03
horsepower (electric)	watt (W)	7.460 000 E+02
horsepower (metric)	watt (W)	7.354 99 E+02
horsepower (water)	watt (W)	7.460 43 E+02
horsepower (U.K.)	watt (W)	7.457 0 E+02
hour (mean solar)	second (s)	3.600 000 E+03
hour (sidereal)	second (s)	3.590 170 E+03
hundredweight (long)	kilogram (kg)	5.080 235 E+01
hundredweight (short)	kilogram (kg)	4.535 924 E+01
inch	meter (m)	2.540 000 E−02
inch of mercury (32°F)	pascal (Pa)	3.386 38 E+03
inch of mercury (60°F)	pascal (Pa)	3.376 85 E+03
inch of water (39.2°F)	pascal (Pa)	2.490 82 E+02
inch of water (60°F)	pascal (Pa)	2.488 4 E+02
in^2	meter^2 (m^2)	6.451 600 E−04
in^3 (volume; section modulus)	meter^3 (m^3)	1.638 706 E−05
in^3/min	meter^3 per second (m^3/s)	2.731 177 E−07
in^4 (moment of section)	meter^4 (m^4)	4.162 314 E−07
in/s	meter per second (m/s)	2.540 000 E−02
in/s^2	meter per second^2 (m/s^2)	2.540 000 E−02
kayser	1 per meter (1/m)	1.000 000 E+02
kelvin	degree Celsius	$t_{°C} = t_K - 273.15$

To convert from	to	Multiply by
kilocalorie (International Table)	joule (J)	4.186 800 E+03
kilocalorie (mean)	joule (J)	4.190 02 E+03
kilocalorie (thermochemical)	joule (J)	4.184 000 E+03
kilocalorie (thermochemical)/min	watt (W)	6.973 333 E+01
kilocalorie (thermochemical)/s	watt (W)	4.184 000 E+03
kilogram-force (kgf)	newton (N)	9.806 650 E+00
kgf•m	newton meter (N•m)	9.806 650 E+00
kgf•s^2/m (mass)	kilogram (kg)	9.806 650 E+00
kgf/cm^2	pascal (Pa)	9.806 650 E+04
kgf/m^2	pascal (Pa)	9.806 650 E+00
kgf/mm^2	pascal (Pa)	9.806 650 E+06
km/h	meter per second (m/s)	2.777 778 E−01
kilopond	newton (N)	9.806 650 E+00
kW•h	joule (J)	3.600 000 E+06
kip (1000 lbf)	newton (N)	4.448 222 E+03
kip/in^2 (ksi)	pascal (Pa)	6.894 757 E+06
knot (international)	meter per second (m/s)	5.144 444 E−01
lambert	candela per meter^2 (cd/m^2)	$1/\pi$ E+04
lambert	candela per meter^2 (cd/m^2)	3.183 099 E+03
langley	joule per meter^2 (J/m^2)	4.184 000 E+04
light year	meter (m)	9.460 55 E+15
liter	meter^3 (m^3)	1.000 000 E−03
maxwell	weber (Wb)	1.000 000 E−08
mho	siemens (S)	1.000 000 E+00
microinch	meter (m)	2.540 000 E−08
micron	meter (m)	1.000 000 E−06
mil	meter (m)	2.540 000 E−05
mile (international)	meter (m)	1.609 344 E+03
mile (statute)	meter (m)	1.609 3 E+03
mile (US survey)	meter (m)	1.609 347 E+03
mile (international nautical)	meter (m)	1.852 000 E+03
mile (UK nautical)	meter (m)	1.853 184 E+03
mile (US nautical)	meter (m)	1.852 000 E+03
mi^2 (international)	meter^2 (m^2)	2.589 988 E+06
mi^2 (US survey)	meter^2 (m^2)	2.589 998 E+06
mi/h (international)	meter per second (m/s)	4.470 400 E−01
mi/h (international)	kilometer per hour (km/h)	1.609 344 E+00
mi/min (international)	meter per second (m/s)	2.682 240 E+01
mi/s (international)	meter per second (m/s)	1.609 344 E+03
millibar	pascal (Pa)	1.000 000 E+02
millimeter of mercury (0°C)	pascal (Pa)	1.333 22 E+02
minute (angle)	radian (rad)	2.908 882 E−04
minute (mean solar)	second (s)	6.000 000 E+01
minute (sidereal)	second (s)	5.983 617 E+01
month (mean calendar)	second (s)	2.628 000 E+06
oersted	ampere per meter (A/m)	7.957 747 E+01
ohm centimeter	ohm meter (Ω•m)	1.000 000 E−02
ohm circular-mil per ft	ohm millimeter^2 per meter (Ω•mm^2/m)	1.662 426 E−03
ounce (avoirdupois)	kilogram (kg)	2.834 952 E−02
ounce (UK fluid)	meter^3 (m^3)	2.841 307 E−05
ounce (US fluid)	meter^3 (m^3)	2.957 353 E−05
ounce-force	newton (N)	2.780 139 E−01
ozf•in	newton meter (N•m)	7.061 552 E−03
oz (avoirdupois)/gal (UK liquid)	kilogram per meter^3 (kg/m^3)	6.236 021 E+00
oz (avoirdupois)/gal (US liquid)	kilogram per meter^3 (kg/m^3)	7.489 152 E+00

To convert from	to	Multiply by
oz (avoirdupois)/in^3	kilogram per meter^3 (kg/m^3)	1.729 994 E+03
oz (avoirdupois)/ft^2	kilogram per meter^2 (kg/m^2)	3.051 517 E-01
perm (0°C)	kilogram per pascal second meter^2 (kg/Pa•s•m^2)	5.721 35 E-11
perm (23°C)	kilogram per pascal second meter^2 (kg/Pa•s•m^2)	5.745 25 E-11
perm•in (0°C)	kilogram per pascal second meter (kg/Pa•s•m)	1.453 22 E-12
perm•in (23°C)	kilogram per pascal second meter (kg/Pa•s•m)	1.459 29 E-12
pint (US liquid)	meter^3 (m^3)	4.731 765 E-04
poise (absolute viscosity)	pascal second (Pa•s)	1.000 000 E-01
pound (lb avoirdupois)	kilogram (kg)	4.535 924 E-01
lb•ft^2 (moment of inertia)	kilogram meter^2 (kg•m^2)	4.214 011 E-02
lb•in^2 (moment of inertia)	kilogram meter^2 (kg•m^2)	2.926 397 E-04
lb/ft•h	pascal second (Pa•s)	4.133 789 E-04
lb/ft•s	pascal second (Pa•s)	1.488 164 E+00
lb/ft^2	kilogram per meter^2 (kg/m^2)	4.882 428 E+00
lb/ft^3	kilogram per meter^3 (kg/m^3)	1.601 846 E+01
lb/gal (UK liquid)	kilogram per meter^3 (kg/m^3)	9.977 633 E+01
lb/gal (US liquid)	kilogram per meter^3 (kg/m^3)	1.198 264 E+02
lb/h	kilogram per second (kg/s)	1.259 979 E-04
lb/hp•h (SFC, specific fuel consumption	kilogram per joule (kg/J)	1.689 659 E-07
lb/in^3	kilogram per meter^3 (kg/m^3)	2.767 990 E+04
lb/min	kilogram per second (kg/s)	7.559 873 E-03
lb/s	kilogram per second (kg/s)	4.535 924 E-01
lb/yd^3	kilogram per meter^3 (kg/m^3)	5.932 764 E-01
poundal	newton (N)	1.382 550 E-01
poundal/ft^2	pascal (Pa)	1488 164 E+00
poundal•s/ft^2	pascal second (Pa•s)	1.488 164 E+00
pound-force (lbf)	newton (N)	4.448 222 E+00
lbf•ft	newton meter (N•m)	1.355 818 E+00
lbf•ft/in	newton meter per meter (N•m/m)	5.337 866 E+01
lbf•in	newton meter (N•m)	1.129 848 E-01
lbf•in/in	newton meter per meter (N•m/m)	4.448 222 E+00
lbf•s/ft^2	pascal second (Pa•s)	4.788 026 E+01
lbf/ft	newton per meter (N/m)	1.459 390 E+01
lbf/ft^2	pascal (Pa)	4.788 026 E+01
lbf/in	newton per meter (N/m)	1.751 268 E+02
lbf/in^2 (psi)	pascal (Pa)	6.894 757 E+03
lbf/lb (thrust/weight [mass] ratio)	newton per kilogram (N/kg)	9.806 650 E+00
quart (US liquid)	meter^3 (m^3)	9.463 529 E-04
rad (radiation dose absorbed)	gray (Gy)	1.000 000 E-02
rhe	1 per pascal second (1/Pa•s)	1.000 000 E+01
roentgen	coulomb per kilogram (C/kg)	2.58 E-04
second (angle)	radian (rad)	4.848 137 E-06
second (sidereal)	second (s)	9.972 696 E-01
slug	kilogram (kg)	1.459 390 E+01
slug/ft•s	pascal second (Pa•s)	4.788 026 E+01
slug/ft^3	kilogram per meter^3 (kg/m^3)	5.153 788 E+02
statampere	ampere (A)	3.335 640 E-10
statcoulomb	coulomb (C)	3.335 640 E-10

To convert from	to	Multiply by
statfarad	farad (F)	1.112 650 E−12
stathenry	henry (H)	8.987 554 E+11
statmho	siemens (S)	1.112 650 E−12
statohm	ohm (Ω)	8.987 554 E+11
statvolt	volt (V)	2.997 925 E+02
stokes (kinematic viscosity)	meter² per second (m²/s)	1.000 000 E−04
therm	joule (J)	1.055 056 E+08
ton (assay)	kilogram (kg)	2.916 667 E−02
ton (long, 2240 lb)	kilogram (kg)	1.016 047 E+03
ton (metric)	kilogram (kg)	1.000 000 E+03
ton (nuclear equivalent of TNT)	joule (J)	4.184 E+09
ton (refrigeration)	watt (W)	3.516 800 E+03
ton (register)	meter³ (m³)	2.831 685 E+00
ton (short, 2000 lb)	kilogram (kg)	9.071 847 E+02
ton (long)/yd³	kilogram per meter³ (kg/m³)	1.328 939 E+03
ton (short)/h	kilogram per second (kg/s)	2.519 958 E−01
ton-force (2000 lbf)	newton (N)	8.896 444 E+03
tonne	kilogram (kg)	1.000 000 E+03
torr (mm Hg, 0°C)	pascal (Pa)	1.333 22 E+02
unit pole	weber (Wb)	1.256 637 E−07
W•h	joule (J)	3.600 000 E+03
W•s	joule (J)	1.000 000 E+00
W/cm²	watt per meter² (W/m²)	1.000 000 E+04
W/in²	watt per meter² (W/m²)	1.550 003 E+03
yard	meter (m)	9.144 000 E−01
year (calendar)	second (s)	3.153 600 E+07
year (sidereal)	second (s)	3.155 815 E+07
year (tropical)	second (s)	3.155 693 E+07

4.3 System of Units

The system of units used by Allis-Chalmers is the International System of Units (SI)

4.3.1 Basic Units

Quantity	Unit	SI Symbol	Formula
length	meter	m	...
mass	kilogram	kg	...
time	second	s	...
electric current	ampere	A	...
thermodynamic temperature	kelvin	K	...
amount of substance	mole	mol	...
luminous intensity	candela	cd	...

4.3.2 Derived Units

Quantity	Unit	SI Symbol	Formula
area	square meter	...	m^2
density	kilogram per cubic meter	...	kg/m^3
electric capacitance	farad	F	A•S/V
electric conductance	siemens	S	A/V
electric field strength	volt per meter	...	V/m
electric inductance	henry	H	V•S/A
electric potential difference	volt	V	W/A
electric resistance	ohm	Ω	V/A
electromotive force	volt	V	W/A
energy	joule	J	N•m
entropy	joule per kelvin	...	J/K
force	newton	N	$kg•m/s^2$
frequency	hertz	Hz	(cycle)/s
illuminance	lux	lx	lm/m^2
luminance	candela per square meter	...	cd/m^2
luminous flux	lumen	lm	cd•sr
magnetic field strength	ampere per meter	...	A/m
magnetic flux	weber	Wb	V•s
magnetic flux density	tesla	T	Wb/m^2
magnetomotive force	ampere	A	...
power	watt	W	J/s
pressure	pascal	Pa	N/m^2
quantity of electricity	coulomb	C	A•s
quantity of heat	joule	J	N•m
radiant intensity	watt per steradian	...	W/sr
specific heat	joule per kilogram kelvin	...	J/kg•K
stress	pascal	Pa	N/m^2
thermal conductivity	watt per meter-kelvin	...	W/m•K
velocity	meter per second	...	m/s
viscosity, dynamic	pascal-second	...	Pa•s
viscosity kinematic	square meter per second	...	m^2/s
voltage	volt	V	W/A
volume	cubic meter	...	m^3
wavenumber	reciprocal meter	...	(wave)/m
work	joule	J	N•m

4.3.3 Multiple and Submultiple Units

Multiplication Factors	Prefix	SI Symbol
1 000 000 000 000 = 10^{12}	tera	T
1 000 000 000 = 10^{9}	giga	G
1 000 000 = 10^{6}	mega	M
1 000 = 10^{3}	kilo	k
100 = 10^{2}	hecto*	h
10 = 10^{1}	deka*	da
0.1 = 10^{-1}	deci*	d
0.01 = 10^{-2}	centi*	c
0.001 = 10^{-3}	milli	m
0.000 001 = 10^{-6}	micro	μ
0.000 000 001 = 10^{-9}	nano	n
0.000 000 000 001 = 10^{-12}	pico	p
0.000 000 000 000 001 = 10^{-15}	femto	f
0.000 000 000 000 000 001 = 10^{-18}	atto	a

*To be avoided where possible

#72 DEFINITIONS & NOMENCLATURE

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